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Leading Article
A Smoother Run 481

Weekly Survey
Signs of Improvement 482
Bridgehead at Copenhagen 482
Trading Prospects in the Middle East 482
Australian Import Cuts 482
U.S. Turbo-Prop Advance 482
Machine Tools for the U.S. 483
G.E.C. Present and Future 483
Reactors Reviewed 483
Marginal Motoring 483
Roads of Concrete 483

Principal Articles
Institution of Naval Architects: Autumn Meeting in Yugoslavia 484
"Merchant Navy" Locomotive Design: Powerful Boiler on an Erratic Engine 485
Engineering Projects in Undeveloped Countries: Conference on Regional Planning and Development 485
The Siting of Nuclear Power Stations: Lord Citrine on Technical Requirements 487
Institute of Metals Autumn Meeting: Transformations in Copper Alloys: Corrosion of Aluminium Alloys 488
Power Reactor Projects Throughout the World: A Comparative Survey of Schemes described at Geneva 490
Design Improved by Study of Service Conditions: Economic Construction of Runways 500
Understanding of Mechanisms Aided by Working Models: A Swiss System for Teaching and Design 501
British Association Meeting at Bristol: Papers by Young Engineers 501
Electricity Supply in Holland: I.E.E. Visit to Research Laboratory and Power Station 502
National Gas Turbine Establishment: (1) Test Facilities 504
Stress Distribution Under Foundations: Mathematical and Photo-Elastic Investigation 507
Testing for Flatness or Straightness: Apparatus Applied to Photographic Plates 510
More Coke for Pig Iron: Extensions to The Stanton Ironworks Plant 512
The 120-MW Bold "A" Power Station 514
Heavy Duty Portable Sander-Grinder 515
Air Controlled Brakes for Motor Vehicles: System for Medium Sizes 516
Earth Moving Equipment: Demonstration at Open-Cast Mining Site 517
Marine Radio Service Depot 517
Rolling-Mill Modernisation at Workington 518
The "Ranger" Mobile Radiotelephone System 518

Obituary
Mr. Thornycroft Donaldson 487
Mr. Arthur Watson 487

Book Reviews
Transistors and Other Crystal Valves 489
National Wages Policy 489

Notes
Safe Transit of Scientific Instruments 487
Large Steel Casting 487
Vacuum Gauge for Testing Pumps 516
An Electric Traction Jubilee 518
Hydro-Electric Development in Scotland 518

The Human Element 520

Personal 486, Commercial 486, Contracts 486, Trade Publications 489, Notices of Meetings 519.

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A SMOOTHER RUN

PROFESSOR LOMONOSSOFF once wrote: "So far as I am aware, the technical schools of Great Britain and America pay very little attention to the problems of railway mechanics." If this be interpreted to include the universities of Britain, it explains in part why after a century and a quarter of practical railway building, there remain unsolved a number of problems in railway mechanics. And it justifies the British Transport Commission's plan to spend £350,000 on a vehicle-and-track testing installation.

The problems which Lomonossoff had particularly in mind were those of traction resistance and of the cost in energy of train movement. In this field his own work, and that of Dalby, Johansen and others, have made it possible to calculate time-displacement curves for any given train with high precision. But associated with the movement of a train along the rails are many other components of movement of the vehicles and their parts; it is about these that knowledge is still imperfect.

To an engineer outside the railway service trying to understand the problems of these movements many questions may occur. How is it that passenger stock deteriorates in service so rapidly that even modern coaches can develop unpleasant oscillation; that what many people still consider to be the best riding coach bogies in Britain are virtually of a design introduced on the Great Northern Railway in 1907; that multiple-unit electric stock is notoriously rough-riding; that, in the experience of British Railways, electric locomotives are more severe on the track than steam locomotives, despite their more flexible wheelbase? A partial answer to some of these questions is that if the passenger were prepared to pay a suitable tariff, so that more complicated bogies could be used, and overhauled more frequently, a high standard of riding could be maintained. This, indeed, was one of the advantages enjoyed by the patrons of the pre-war L.N.E.R. high-speed trains in return for their supplementary fares.

It is here that fundamental research may help. How can a simple bogie be made to attain and maintain a standard of riding which shows an improvement over its predecessors comparable, say, with the improvement in the riding of motor vehicles in the last 30 years? In the past, *ad hoc* experiments have often been made in the design of bogies, but there have rarely been laboratory investigations or mathematical analyses. The analysis of road tests is extremely difficult because of the number of variables, such as the day-to-day condition of the track.

It was not until recent years that a British railway encouraged research on this subject in a university. The first mathematical treatment of the riding of a vehicle was that of Davies in Cambridge in the 1930's. This included an analysis of the motion of a single axle and of a bogie, and experiments were made with a model bogie launched along a length of straight track by a catapult. Full-size work in support of this was conducted by the L.M.S. Further work was done with a single axle running on the rims of a pair of steel rings, like a locomotive testing plant. Later, at Southampton University, the same principle has been extended to a complete bogie, but the work has not yet covered the most complex motions which can develop at high speed.

Another related problem arose during the war when a number of four-wheeled vehicles were derailed while running at passenger-train speeds. An investigation was made at Swindon, which included a detailed mathematical analysis of the motion of a van over a known stretch of line. As a result of these investigations, the running of four-wheeled vehicles in expresses was restricted, and vehicles with longer wheelbases were built after the war.

Both these lines of research have an important bearing on future developments. Not only do present conditions demand a more detailed knowledge of the subjects, but the modernisation programme of British Railways proposes that both passenger and freight trains should be run at higher speeds. This will take freight wagons to speeds at which dangerous oscillations have been known to develop, and at speeds double those of to-day passenger coaches might develop flange climbing or other movements not before encountered.

Against this background the announcement that the railways have set up a research team to deal with "vehicle-and-track" testing is very apposite. A stretch of track is to be laid near Derby for investigations into the effect on the motion of vehicles of such variables as the condition of wear of the vehicle and track. Although it will only be possible to reach speeds up to 60 miles an hour, this will be an invaluable research tool both to mechanical and civil engineers. It will open the way to investigating in advance problems which will arise with large-scale electrification. Not only can the characteristics of the vehicle be varied, but it will also be possible to test the effects of, say, using different types of rail with different fastenings, and of eliminating rail joints by welding. That these problems are not confined to Britain is shown by a competition at present being held by the Office for Research and Experiment of the International Union of Railways for the best solution to the problem of the "hunting" of vehicles. Railways are old, but they are still imperfectly understood.

Weekly Survey

Cover Picture. *No. 70003, "John Bunyan", is leaving Liverpool Street Station, London, with an express passenger train for Cromer. The locomotive is one of the Britannia class—the first of the range of standard designs produced by British Railways after nationalisation.*

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SIGNS OF IMPROVEMENT

Current indicators of the health of the economy suggest that the trend changed for the better during July and August. Sterling has been stronger of recent weeks (and the state of confidence abroad in sterling is a vital factor at present) and the recent figures of industrial production published by the Central Statistical Office suggest that steady, if unspectacular, progress is being made in recovering from the effects of the dock and railway strikes in the early summer. Provisional figures for August put industrial output at 118 to 119 compared with 113 in August last year. Since the index for July this year was 121 compared with 117 in July, 1954, the drop between July and August this year looks like being 3 points compared with 4 points last year, which is an encouraging sign especially as the fall this year is from a somewhat higher level than last year. And as the coal industry has had a disappointing summer and the output of the gas and electricity industries must have been affected somewhat by the fine weather, while textiles too have shown no resilience of late, a good deal of the buoyancy in production must have been contributed by the metals and engineering industries.

But the challenge to British goods in export markets continues. A reminder of the need for flexibility in export policy is given in the latest issue of the Treasury's *Bulletin for Industry*. The gist of its argument is that British exporters should realise the opportunities which exist for British goods in Western European markets now that the will to expand production and productivity in Western Europe is so much more evident than it was some years ago. For some time to come, the bulletin goes on, the industrialised countries of Western Europe may provide better opportunities for expanding exports than the primary producing countries which are the big traditional markets for British capital and consumer goods. It would be wrong to read into this argument that the long-term prospects for British exports lie in industrialised markets rather than in countries which produce primary goods, but as an argument for a short-term change of emphasis it has much to commend it.

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BRIDGEHEAD AT COPENHAGEN

If this country is to continue to build up its export trade with north western Europe against severe German competition, there is no better place to intensify efforts than Denmark. It is clear from the elaborate arrangements which have been made under the joint royal patronage of both kingdoms that the British Exhibition in Copenhagen which was opened last week is a major offensive on the Danish market by British manufacturers.

The United Kingdom is Denmark's best customer and takes 40 per cent. of that country's exports. Western Germany is of much less consequence to the Danish economy so far as exports are concerned since only 13 per cent. of the Danish export trade goes to that country. Almost 30 per cent. of total Danish imports come from the United Kingdom and the average Dane buys over £18 worth of British goods every year. The United Kingdom's exports to Denmark, in fact, reached the high figure of £82 million in 1954. It is therefore clear that the trade relationship between the two countries is of prime importance to both of them. Recently, the trade balance has been notably in Denmark's favour and the settlement of this balance involves this country in a gold payment under E.P.U. arrangements. There is thus a short-term need for this country to improve its trade balance with Denmark as a means of helping to control the gold drain on its resources, and also the long-term need to build up trade in what has been for generations a friendly market.

The exhibits are designed to make a big impact on the Danish public but there is an important section of the exhibition dealing with products and services of interest to industry. There is a display by the United Kingdom Atomic Energy Authority, and the General Electric Company Limited is showing a model of a possible nuclear power station of the future, as well as equipment connected with guided missiles. Ten of I.C.I's 12 manufacturing divisions are exhibiting a wide range of products from drugs to dyestuffs. The textile side of the Exhibition is a highly important one since British textiles have recently suffered something of a setback in the Danish market. The Radio and Electronic Component Manufacturers Federation are occupying a prominent position, and 31 manufacturers within the Federation are exhibiting on stands or have taken display space.

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TRADING PROSPECTS IN THE MIDDLE EAST

British manufacturers would do themselves and their country a service if they recognised, in practical terms, the trading opportunities that are being created in the Middle East "oil" States by the flood of royalty payments by the oil companies. The revenue of Iraq, Persia, the Persian Gulf States (Kuwait, Bahrein and Qatar) and Saudi Arabia has been recently at the rate of some £200 million a year and is likely to rise to £300 million within two years. Political conditions are relatively stable and trading conditions better than they have ever been. British exports in the first half of the year were at the annual rate of nearly £70 million (20 per cent. more than in 1954) and rising sharply. So far, the bulk of these exports has been provided by suppliers of materials and equipment for the oil industry and for major schemes of construction and irrigation. While the volume of this work will tend to increase—for example, harbour facilities will have to be constantly extended—there are signs that a new demand is arising for consumer goods.

This information was given at a Press conference last week by Mr. A. R. W. Low, the Minister of State, Board of Trade, supported by H.M. Ambassadors in Baghdad and Teheran and by H.M. Political Resident in the Persian Gulf. Their aim was to arouse widespread interest in what they considered a profitable and immensely promising market for the British exporter. The Ambassadors gave an undertaking that any industrialist wishing to establish relations with the countries they represent will receive all possible assistance. Structural engineering materials and equipment will continue to be in great demand, and as roads, railways and harbours are constructed the demand for transport equipment will rise. The "oil" countries are very willing to send engineers for training in the United Kingdom, all expenses paid, and if vacancies can be found the situation should improve; the alternative—that they should be trained elsewhere, in Germany, the United States, France, etc.—would not assist the long-term British prospects. The message of Mr. Low and of the ambassadors is that the opportunities are there, the timing is right, the Government will help—but the ball is at the exporters' feet.

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AUSTRALIAN IMPORT CUTS

Mr. R. G. Menzies' axe has fallen, and for the second time British exporters to Australia, which is to most of them the largest export market for their products, have to scurry around the rest of the world to find new outlets. New Zealand also wields the axe, but only on imports of motor vehicles, which are to be one-third less in 1956 than in 1955. The Australian restrictions will vary according to the importance to the economy of the products concerned. Non-essential imports, among which motor vehicles are included, will be reduced by one quarter, and few items affected will escape with a cut of less than 10 per cent. Only machinery "for essential industry" will remain unaffected.

Altogether the restrictions are expected to reduce the value of imports by £A80 million (£64 million) in a full year, but as import licences already granted will not be revoked, the reduction for the financial year ending June 30, 1956, is not expected to exceed £A20 million. Among the category "B" imported items, most of which are subject to a cut of 25 per cent. on the current level, are washing machines, radio sets, clocks and watches and a wide range of domestic electrical appliances. The opportunity is again taken to promote local manufacture and assembly and the quota for unassembled motor vehicles (completely knocked down) is to be reduced by 12½ per cent. only. British manufacturers with assembly facilities on the spot will therefore escape relatively lightly.

The inevitability of import restrictions has been plain for some months: there has been a fall of £A58 million in Australia's overseas currency reserves since June 30, to £A370 million and, as Mr. Menzies pointed out, it would be disastrous if the reserves were allowed to fall below £A300 million. There is talk of setting up an export credit scheme, presumably to stimulate exports of manufactured goods, but it will take time to reduce production costs sufficiently for Australian products to be competitive on a broad front. Meanwhile the country continues to depend on exports of primary products, particularly wool, and any fall in the annual wool cheque (it may be £60 million down this year) is reflected immediately in the balance of payments position. Yet earnings on exports of primary products have made possible a vast industrialisation programme without extensive borrowing abroad. This is in itself a major achievement but during the time required for secondary industry to reach maturity and to become competitive, the adjustment of imports by the quota system would seem inevitable.

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U.S. TURBO-PROP ADVANCE

The success story of the turbo-prop airliner, begun in this country by the Vickers Viscount less than three years ago, is being continued in the United States by the Lockheed Electra. Eastern Airlines, one of the biggest U.S. domestic operators, have placed an order worth £45 million with the Lockheed Aircraft Corporation. The order, which includes 40 Electras and 10 piston-engined Super-Constellations, is said to be the largest ever recorded in the history of commercial aviation. The company have also taken an option on an additional 30 Electras.

These orders bring the Lockheed company's commercial order book to £110 million, representing 25 per cent. of their total business compared with only 12 per cent. a year ago. Earlier this year another large U.S. operator, American Airlines, placed an order for 35 Electras valued at £23½ million. These very large purchases of commercial aircraft—Vickers have orders valued at about £60 million for the Viscount and are producing these airliners at the rate of five a month—suggest that the reductions in military requirements may well be less painful than had been anticipated. Vickers plan to increase the rate of production to six a month next year, and if the order book warrants it, they will double this rate.

The Lockheed Electra has been designed to incorporate the U.S. Allison Type 501 turbo-prop engine, but there is a possibility that British engines will be fitted. The president and engineering vice-president of Lockheed visited this country during the summer to study British turbo-prop design and had discussions with Rolls-Royce, Bristol, and D. Napier and Son.

The developments in the U.S. suggest that

Britain's long lead in medium-range turbo-prop airliners has been substantially shortened. Should the Lockheed Electra be as successful as the Vickers Viscount, the prospects of exporting the latter to the U.S. would obviously be diminished. On the other hand, Mr. Peter Masefield's estimate that 500 aircraft of this type would be needed leaves room for two major producers (Weekly Survey, August 19). In the category of long-range turbo-prop airliners, no serious competitor to the Britannia has yet emerged, and in the medium-range market the relatively-long flight experience of the Viscount will doubtless weigh in its favour for some years to come.

* * *

MACHINE TOOLS FOR THE U.S.

The tangle which has developed in American trade policy over the Joseph Dam contracts, the bicycle tariff and compensating tariff and adjustments on other goods may, have another strand added to it before very long. The U.S. Administration is planning to buy 65 million dollar's worth of tools which will become stand-by facilities for the production of ships' turbines.

It is reported that a special inter-agency committee will decide in the near future whether foreign manufacturers are to be allowed to bid on these contracts. It is already known that domestic tool makers are going to ask for protection. A possible compromise might be that foreign makers will be allowed to bid for a limited quantity and for certain kinds of tools only. Since the decision will be taken when the American engineering industry is experiencing boom conditions at what is normally a seasonably busy period, the decision may be more favourable to foreign manufacturers than it would have been in the spring of this year. The production of cars and lorries in the U.S. has been running in recent weeks at 17 per cent. higher than the corresponding level of 1954, and engineering construction awards are 20 per cent. above the level of a year ago. It is to be hoped that the decision, when made, is not such that foreign makers will be allowed to quote but will not be encouraged to do so. This issue, however, may provide a useful opportunity of assessing whether the U.S. Administration's attitude to foreign bids has been influenced by unfavourable foreign reactions to the most recent Joseph Dam episode.

* * *

G.E.C. PRESENT AND FUTURE

The General Electrical Company of to-day are one of the giants of British industry, employing 70,000 people and operating over 40 factories in the United Kingdom. During the past eight years they have spent some £20 million on expanding manufacturing and research capacity and added 25,000 to their labour force. Reserves amount to nearly £30 million, and profits for the year ending March 31, after deducting £1·4 million for depreciation, totalled £7·5 million—more than 12 per cent. higher than at any time during the company's history. These facts were given by the chairman, Sir Harry Railing, at the 55th Annual General Meeting of the company.

The highlights of recent achievements are probably the development of new semi-conducting compounds (which is described as " one of the greatest advances in electrical engineering since the introduction of the thermionic valve "), the progress made in the development of atomic power station plant and electric furnaces for the production of metallic uranium; and the development of a system of direct cooling of rotor windings which will make possible the building of single generating units in excess of 200 MW. Sir Harry rightly emphasises the research activities of his company, most of which will take many years before they mature and many more before they become commercially viable. In too many cases this is misunderstood by shareholders, and yet the nation's livelihood in the future depends on this type of heavy investment.

The chairman points out that the company's manufacturing capacity has of late increased at a higher rate than the incoming flow of orders, and that although the order position for all capital equipment is extremely good, the short-term prospects for electric domestic appliances are not so favourable. Sir Harry's remarks on the outlook are best quoted as they stand: " The possibilities of progress in the electrical industry all the world over are almost unlimited. Electric power forms the basis for increased raw material and food production, and for progress in every industry. The world demand for our products therefore is hardly limited at this juncture. The present demand is accentuated by the development of backward countries, the increase in the world's population and the accelerated progress of technology. The degree to which the demand can be satisfied is only conditioned by the availability of capital and the spending capacity of consumers at home and abroad."

* * *

REACTORS REVIEWED

The rate of engineering development is directly related to the numbers engaged upon it, and the more people there are aware of the problems in any field the quicker they will be solved. It is with this in mind and to help the engineer get a firm footing on the " moving vehicle," that we have given the greatest possible space to reports on the Geneva Conference, and endeavoured, by means of explanatory notes, supplementary articles and a glossary, to make the subject intelligible to the non-specialist.

In the present issue we publish an article which should further contribute to this end. It provides brief descriptions of all the power reactors considered at the Conference and compares them from technical and economic points of view. For quick reference, the characteristics of the reactors are summarised in tabular form with schematic diagrams to indicate their principles of operation. In preparing the article, Mr. G. W. K. Ford, of Harwell, has assembled most of the available information on power reactors throughout the world, and since much of this data was not generally released until the Geneva Conference, his review is probably the most comprehensive treatment of the subject yet published.

* * *

MARGINAL MOTORING

Last week's Frankfurt Motor Show illustrated the increasing popularity of a type of personal transport which may be called the scooter car, since it stems from dissatisfaction with the lack of weather protection on the motor scooter, a vehicle which has now passed the peak of its post-war popularity.

Former aircraft manufacturers, Messerschmitt, Heinkel and Dornier, are fostering the movement. The vehicle has evolved through the three-wheeler, like the Messerschmitt, with its two tandem seats under a plastic " bubble " top, to the four-wheeler like the Isetta, with an egg-shaped body seating two side by side. These two are sold in Britain, at prices heavily inflated by uplift, duty and purchase tax, but there is also the little Goggomobil, built at the rate of 60 a day by an ex-scooter manufacturer, with two seats for adults and two for children, and offering surprising speed, hill-climbing capacity and riding comfort over very rough surfaces, with an engine of only 300 c.c.

Heinkel's prototype seems to draw inspiration from Messerschmitt for chassis and Isetta for bodywork, while Dornier's four-wheeler has two bench seats back to back, with front and rear doors which hinge upwards. There are several others competing for the market. Most of them are made and equipped in a way likely to inspire pride of ownership, and they offer all the performance the average British motorist ever uses, with an ability to cruise at 45 to 50 m.p.h., and to cover 60 to 80 miles on a gallon of fuel. They all use rear-mounted air-cooled engines of not more than two cylinders, driving the rear wheels.

In a slightly larger category is the Lloyd, with a two-cylinder two-stroke engine of 386 c.c. at the front, driving the front wheels. This is really a miniature car, selling at the rate of 5,000 a month, which puts it third in the list of German car sales. It is now made with a new two-cylinder four-stroke air-cooled engine with an overhead camshaft, developing 19 b.h.p. from 596 c.c. Such vehicles would be very suitable for the crowded roads of Britain, but success demands serious engineering and a considerable tooling investment. It is a field which has so far been ignored by major British manufacturers. To compete would require a revolution in the conventional British outlook on vehicle design, but it might be worth while for someone to make the effort, now that markets for conventional cars are becoming so competitive and little is being done to improve the roads.

* * *

ROADS OF CONCRETE

It is always interesting, and sometimes very informative, to have a peep over the fence and see what your neighbour is doing. So often he is doing the same jobs as you, and many useful hints can be gained from his experience. The opportunity for such a glimpse was afforded to a group of engineers, the Committee for Co-operative Research between the Road Research Laboratory and the Cement and Concrete Association, when in 1954 they made a tour of inspection of concrete motor roads in Belgium and Germany. In view of the road building plans in this country, their authoritative report on the performance of these roads during 15 years under heavy traffic is worth attention (*Concrete Roads in Belgium and Western Germany*. H.M. Stationery Office, 3*s*.).

During their 12-day visit, the committee rode over some 178 miles of road in Belgium and 296 in Germany. Inspection was made of an additional 46 miles and 343 miles in the two countries, as well as experimental lengths and roads under construction. The report is extremely favourable to concrete, particularly the German motor-roads, where the absence of hold-ups due to maintenance work was very noticeable. In both countries the actual surface of the roads was in excellent condition in spite of the enormous increase in traffic since they were originally built. Such defects as were noticeable were mainly due to failure of the sub-grade—a failure which modern methods and knowledge of soil mechanics would almost completely prevent. The traffic on some of the dual-carriageway roads in Germany increased by 20 to 30 per cent. during the year 1953, and some sections are now carrying 20,000 vehicles a day, of which 40 per cent. is commercial traffic. Many of these commercial vehicles are heavy long-distance transport trucks with trailers, travelling at speed, yet very little surface maintenance is required.

Under this traffic the main trouble appears to be sinkage of the slabs due either to poor compaction of the sub-grade or to the finer particles being " pumped " out by the passage of the vehicles. In either case, methods have been devised for raising the slab mechanically or by compressed air and for injecting a fill of sand. Using dowels between slabs would check the relative sinkage—a view shared by both British and German engineers. In both Belgium and Germany there is a tendency to use longer slabs—up to 50 ft. in Belgium and up to 1,310 ft. in an experimental section in Germany. Also in the latter country, there are sections where the expansion joints have been cut in the hardened concrete by means of a carborundum saw.

The concrete roads of Belgium and Germany were worth visiting and studying, for a surface which will last for 15 years (some, 20 years) under intensive traffic coupled with extremes of heat and cold is not to be despised.

THE INSTITUTION OF NAVAL ARCHITECTS

AUTUMN MEETING IN YUGOSLAVIA

Since the Institution of Naval Architects first went abroad for a Summer or Autumn Meeting (in 1895, to Paris) they have been to France on three further occasions, to Holland and to Italy twice, and once each to Germany, Belgium and Denmark. This year they broke new ground by visiting Yugoslavia on the invitation of the Yugoslav Society of Naval Architects (Drustvo Inzinjera i Tehnicara Brodogradnje), where, under the distinguished patronage of the President of the Republic, Marshal Josip Broz Tito, they held a four-days meeting at Rijeka (the former Fiume) and thereafter cruised south down the Dalmatian coast to the island of Korcula and to the ports of Dubrovnik, Split and Sibenik, and thence back to Rijeka. Most of the party returned directly from Rijeka, but some remained in the country for a further two days, to take the opportunity of seeing the new testing-tank establishment, under construction near Zagreb.

The meeting began on the morning of Monday, September 19, with an official reception in the Kvarner Hotel, Opatija, at which the proceedings were formally opened by Professor Ing. S. Silovic, Professor of Naval Architecture at the University of Zagreb and Superintendent of the Tank Establishment (Brodarski Institut), who is a Member of the Institution of Naval Architects. At his invitation, Vice-Admiral Jerkovic, Commandant of the Yugoslav Navy, then delivered an address of welcome on behalf of the President and people of the Republic, which was subsequently repeated in English by Captain V. M. Pulko, Yugoslav Navy.

Professor Silovic, in his opening remarks, explained that he was deputising for the President of the Yugoslav Society, Ing. A. Jagodnik, who was prevented by illness from being present. He extended a welcome to Vice-Admiral Jerkovic, as representative of the President, and asked him to convey to Marshal Tito the thanks of the meeting for having honoured them with his patronage. He greeted also the British Naval Attaché, Commander D. R. H. Ferguson, R.N., who was present as the representative of the British Ambassador in Belgrade; and Sir Harold Yarrow, Bt., C.B.E., Honorary Vice-President of the Institution, who acted as its principal representative in the absence of the President, Viscount Runciman of Doxford, who was unable to be present. Sir Harold, the Professor recalled, had been connected for a number of years with the Yugoslav shipbuilding industry, and many of the Yugoslav naval architects present (including Professor Silovic) had had the pleasure of being associated with him during that period.

Vice-Admiral Jerkovic said that he was honoured to welcome the members of the Institution in the name of Marshal Tito, who was prevented by affairs of State from greeting them in person. That was a matter for general regret, for Marshal Tito was himself a former shipbuilder and, in the Vice-Admiral's words, " there are few people who could understand you so well." He hoped that the meeting would be successful, and sent his best wishes for the future prosperity of the Institution.

In the technically advanced world of to-day, Vice-Admiral Jerkovic continued, science could not be kept within the narrow borders of States. They found it logical, therefore, that the old-established Institution of Naval Architects should acquire more and more an international character, thus helping to develop the knowledge and the art of shipbuilding throughout the world. They were happy that Yugoslavia had attained to such a technical level that their naval architects and technicians could collaborate with the Institution and learn from the experience of others. Yugoslavia had an ancient maritime tradition, but had suffered much at the hands of many invaders throughout the centuries. The members would be able to see, however, how much had been done in the ten years since the country was liberated, notwithstanding the handicaps against which they had to contend. He wished them success in the work on which they were engaged.

Vice-Admiral Jerkovic was followed by Mr. Roate Kesic, Director of the Yugoslav State Shipping Line (Jadranska Linijska Plovidba), who, on behalf of the Yugoslav Shipping Association, expressed the hope that the meeting would lead to a closer co-operation between the several countries represented, in both technical and shipping matters; sentiments which were endorsed by Mr. Micho Gotic, the Mayor of Opatija.

Professor Silovic then presented copies of the first two volumes of the *Pomorska Enciklopedija* —claimed to be the first comprehensive encyclopædia of shipping, now in course of publication in Yugoslavia—to Sir Harold Yarrow, for the Institution library, and personal complimentary copies to Sir Harold himself, to Rear-Admiral Sir Arthur Hall, K.B.E., C.B. (Honorary Treasurer of the Institution), to Professor Dr. Ing. G. Kempf (formerly Superintendent of the Hamburg Ship-Model Tank), to Professor Dr. Ing. W. P. A. van Lammeren (Superintendent of the Netherlands Ship-Model Tank at Wageningen) and to Monsieur A. Augustin-Normand.

Sir Harold Yarrow, acknowledging the welcome extended to the Institution, said that he must first convey to the meeting the regret of its President, Lord Runciman, that he was unable to be present. He thanked Professor Silovic and the other members of the Yugoslav Society of Naval Architects for having invited the Institution to hold their Autumn Meeting in Yugoslavia, for all the arrangements that had been made to ensure its success, and for the gift of the imposing volumes of the *Pomorska Enciklopedija*. Those who, like himself, already knew Yugoslavia, were always impressed by the kindness and hospitality extended to visitors; and those who were visiting the country for the first time would certainly feel that they were among friends.

Sir Harold then announced that Marshal Tito had honoured the Institution by accepting the diploma of Honorary Membership, which he had deputed Vice-Admiral Jerkovic to receive on his behalf. Amid applause, he presented the diploma to the Vice-Admiral.

AN INTRODUCTION TO YUGOSLAVIA

The formal ceremonies having been concluded, Professor Silovic then delivered, in fluent English, what was described in the programme as " an informal talk on Yugoslavia," illustrating his remarks by reference to a large wall map.

The name Yugoslavia (or as it is spelt in the country, Jugoslavia) signified, he explained, the land of the South Slavs. The country occupied the central and north-western parts of the Balkan Peninsula. The northern part consisted of rich and fertile plains through which a number of navigable rivers flowed into the Danube. The remainder was mountainous and difficult of access; the main mountain ranges being parallel with the coast, approach from the sea was almost impossible. These ranges constituted a permanent boundary between east and west, and, in earlier eras, separated the Roman Empire from Byzantium. This separation was reflected in the national culture and its consequences persisted to the present day.

The Federal People's Republic of Yugoslavia contained five nations, but actually six republics—those of Serbia, Croatia, Slovenia, Crna Gora (Montenegro), Macedonia and Bosnia-Herzegovina—the last of which, however, was not inhabitated by a separate nation. The total population was about 18 millions. About four-fifths of the people spoke the same language, Serbo-Croatian. The Slovenes and the Macedonians possessed their own Slavic languages, which were very similar but used a different alphabet. The natural resources of the country included rich deposits of lead, copper and bauxite ores, and vast woodlands of oak and pine; these constituted the principal exports. There were also rich water resources, though only partly exploited, and during the past 10 years power stations, blast furnaces, steel, copper and aluminium works had been built.

The major part of the coastline belonged to Croatia and was inhabited by Croats, who supplied practically all the seafaring personnel and were predominant in the shipbuilding industry. The principal trading port was Rijeka; others were Sibenik (formerly Sebenico), Split (Spalato), Ploce, which was under construction, and Dubrovnik (formerly Ragusa). The Slovenian harbour, Koper, was being extended, and a new one, Bar, was under construction in Crna Gora, to form the terminal for a new railway line from Belgrade. Seaborne trade with other countries amounted to between four and five million tons yearly, but about 60 per cent. of it was carried in ships of other flags, the Yugoslav mercantile marine fleet, which suffered severely during the second World War, being insufficient for present requirements. The whole of the Yugoslav shipping served the cause of the Allies in that war, 84 per cent. of the total tonnage being sunk, with the loss of some 300 lives. Immediately after the war, only about 100,000 tons remained, most of it consisting of old and worn-out ships, but the tonnage had been doubled in the past ten years and most of the new vessels had been built in Yugoslav shipyards.

Wooden shipbuilding was still practised at many centres, especially among the islands. The large yards, building steel ships, comprised the Uljanik yard at Pola (the former Austrian naval dockyard, which would celebrate its centenary in 1956); the 3rd May yard at Rijeka, which would be 50 years old in 1956 (the name commemorates the date of liberation in 1945); the Tito yard at Kraljevica, so named because Marshal Tito was employed there as a workman in 1926–27; and the Split yard, founded about 30 years ago.

All the important enterprises in the country, including the shipyards and the shipping companies, were nationalised, and were managed by those employed in them, who elected a Workers' Council, which was the highest administrative authority. The Council (which met two or three times a year, as circumstances required) elected an administrative committee, who, in conjunction with the Director, dealt with all current questions of production. The members of the committee, and its chairman, continued to work at their respective trades or occupations and functioned as a committee only when assembled in their full number. The Director, who became automatically a member of the committee, was elected in competition on the nomination of the committee, and the election had to be confirmed by the People's Committee of the municipality in which the establishment was situated.

The Government prescribed the amount to be paid by the enterprise on account of depreciation and by way of interest on the invested capital, but otherwise the business was completely independent of Government direction or regulation. It was not at liberty, however, to dispose of the whole of the profits made; about half was paid to the central administration of the State, about a quarter went to the town and republic in which the establishment was located, and the rest was at the disposal of the Workers' Council. If they elected to distribute it among the employees, the individual shares were fairly heavily taxed, but no tax was levied on any money that the Council decided to plough back into the business or to devote to such amenities as workmen's dwellings, schools, etc.

Professor Silovic's address, which was warmly acclaimed, concluded the business of the opening session.

To be continued

"MERCHANT NAVY" LOCOMOTIVE DESIGN

POWERFUL BOILER ON AN ERRATIC ENGINE

During 1952, and extending over periods in 1953 and 1954, a series of comprehensive tests were conducted at the Locomotive Testing Station, Rugby, with one of the well-known "Merchant Navy" class mixed-traffic locomotives of the former Southern Railway. The results of these experiments have now been released by the British Transport Commission and form the subject of test report bulletin No. 10.*

Locomotives of this type, it may be remembered, were introduced in 1941 for main-line working. The design, which includes several novel features, was due to Mr. O. V. Bullied, Chief Mechanical Engineer, and though they have given a good account of themselves in heavy and fast services and proved capable and effective, the tests now completed have shown them to be relatively uneconomical in fuel consumption in relation to the power developed at the drawbar.

The more important features in the design of these locomotives include the provision of thermic syphons in the firebox and a special type of multi-jet blast pipe. A further innovation was a special arrangement of the valve gear, which is of the Walschaerts type operating outside-admission piston valves for the three cylinders. The valve gear and the motion for the single inside cylinder are entirely enclosed in a casing, the mechanism being splash lubricated.

The very complete trials carried out with this engine embraced experiments with two different blast pipes—the standard multi-jet, and a single blast pipe—and with and without thermic syphons in the firebox.

Unfortunately difficulties are reported respecting the valve gear. It was found that the actual cut-offs have no definite or consistent relationship to the setting of the reversing gear. This irregular working made it impossible to control power output by adjusting rates of admission. Thus for lower rates of working, regulator openings had to be adjusted to suit the required evaporative rates and steam production.

It appears also that some troubles were experienced by the engine slipping on the plant, which made it actually dangerous to attempt maximum rates of power output. These difficulties effected the performance of the boiler, which could not be worked up to maximum output. With Blidworth coal, used for all locomotive tests, an actual rate of 33,300 lb. of water per hour was sustained, and with Bedwas coal the evaporation reached 37,000 lb. When using South Kirkby coal an hourly evaporation of 39,000 lb. of water was maintained for one hour or more, and a maximum of 42,000 lb. of water per hour was held for a period of 20 minutes without any indication that the limit had been reached.

Trials with the modified boiler without thermic syphons were completed early last year. The results indicated there was virtually no difference in the maximum output when using Blidworth coal, for the reason that any heat not taken up in the firebox was readily absorbed by the tubular heating surfaces, and the additional heat carried by the gases liberated in the firebox was found to increase the temperature of the superheated steam. The single blast pipe fitted experimentally was satisfactory in ordinary working, for though maximum evaporations were reduced in comparison with the standard multi-jet arrangement, the locomotive could meet all requirements. When fired with South Kirkby coal, the cylinders developed a maximum of 2,485 i.h.p. at 75 miles an hour, and at the same speed with Blidworth coal the power was about 2,120 i.h.p. With the latter fuel the drawbar horse-power was 1,600, or slightly more at speeds of 40 to about 60 m.p.h.

The test results obtained with this engine are of considerable interest and are especially so where they concern the boiler, which seems to have a very high steaming capacity. The extensive nature of the investigations carried out reflects great credit on the testing personnel, especially on account of the rather serious difficulties encountered during the Rugby trials.

* *Performance and Efficiency Tests of Southern Region "Merchant Navy" Class, 3 Cyl. 4-6-2 Mixed Traffic Locomotive.* British Transport Commission, 222 Marylebone-road, London, N.W.1. (10*s.* net.)

ENGINEERING PROJECTS IN UNDEVELOPED COUNTRIES

CONFERENCE ON REGIONAL PLANNING AND DEVELOPMENT

The Conference on Regional Planning and Development, held last week at Bedford College, London, took place in an atmosphere of publicity unusual for such a subject. This was due to the action of the Home Office in warning Civil servants not to attend, and of the Foreign Office in advising foreign governments that the sponsors of the Conference were politically undesirable. It was difficult to detect political bias of any sort, either in the organisers or in those who presented the objective and interesting papers, but the effect of the Government's warnings was to deprive the Conference of a number of visitors, official and unofficial, from this and other countries and from a number of Colonial territories.

The object of the organisers, who had the support of many national and international bodies, including the Federation of British Industries, the Association of Consulting Engineers and the Royal Institute of Public Administration, was to bring together representatives of a number of different professions associated with the type of large-scale development undertaken by governments, by the special agencies of the United Nations, by voluntary bodies and by private enterprise, with the ultimate aim of establishing a centre for Regional Planning and Development in London. Through the assistance of the Halley-Stewart Trust the foundations of a library have already been laid and 2,000 books are housed in the Town Planning School of the University of London. Among those attending the Conference were engineers, architects, town planners, agriculturalists, economists, social scientists and administrators.

The scope of the discussions covered such diverse enterprises as the Tennessee Valley Authority, the Volta River project, the widespread Community Development Project in India and a privately sponsored town-planning scheme in North Italy; as well as descriptions of reconstruction work in Upper Silesia, public health programmes in the reclaimed land of the Dutch Polders and in a Nigerian town, and projects in a number of colonies.

VOLTA RIVER PROJECT

The emphasis of all the main speakers was on the necessity, in preparing regional plans, to study not isolated phenomena but human beings in their environment. This can only be done when development is considered as an amalgam of economic, social and physical factors which must be planned comprehensively. It also requires that the area for development should be a single ecological whole: that is, a true region. It was for this reason that, in the case of the Volta River Project, the parties concerned—the United Kingdom and Gold Coast Governments and the aluminium companies—agreed to set up a Preparatory Commission, under a special commissioner, to examine the feasibility of the project from all angles and to assist in the formulation of the statutes and agreements that would govern the project if it was undertaken.

In his paper, which, under the circumstances, had to be read for him, Mr. J. H. Liverman of the Preparatory Commission explained that the Commission worked as an impartial agency whose reports would be considered by the various parties to the proposed agreement. The subjects being investigated were the technical problems associated with reconstruction of the dam and the new railways; the human factors arising from the recruitment of a large labour force on the site, including training problems; the sociological results of the impact of a major industry on a society where large-scale manufacture is unfamiliar, the requirements of housing and town planning, of feeding and of health and sanitation; the relation of the project to agriculture, fisheries and forestry; communications; population disturbance; and, finally, an appreciation of the economic and financial aspects of the scheme.

It was this paper that brought out most sharply the essential dilemma of all large-scale plans of this nature. It was strongly criticised on the grounds that such a detailed inquiry took no account of the urgency of the Volta River Project (which was first considered in 1924). Most speakers, however, were emphatic on the need to ensure adequate preparation in order to avoid mistakes due to inadequate knowledge of, for instance, climatic conditions and, in particular, to ensure that full consideration had been given to the effect on the people involved and that their willing co-operation and support had been obtained.

T.V.A.

This scheme, which will have a capacity of about 500 MW of electricity, is tiny beside that of the T.V.A., the administration of which was described by Dr. E. A. Acherman, who was its assistant general manager, and which now has an installed capacity of about 22,000 MW. In its original conception T.V.A. was not an overall planning scheme; its only powers were to construct river control works and power transmission lines, to authorise or refuse permission for construction of non-federal works on the river, and the right to obtain properties necessary for its business. The T.V.A. administration operated by encouraging state and local institutions to undertake appropriate action in their own regions; by means of demonstrations in farming, town planning, re-afforestation, timber mill operation, public health, mineral research and other activities; by using cheap power, seedlings, technical services and cheap credit as "leverage" devices to encourage local improvements by farmers and business-men; by promoting "countervailing" economic and social forces such as trade unions and co-operatives; and by efficiently operating an indivisable water control system and a completely integrated electric power system for the entire river basin. The whole emphasis was on decentralisation and the encouragement of local and individual initiative.

INDIAN COMMUNITY PROJECT

It was with the same object of avoiding bureaucratic centralisation and enlisting the

co-operation of the people themselves in their own betterment that the Indian Community Project described by Mr. T. Swaminathan was started in an attempt to bring about a gradual transformation of the social and economic life of the villages. The activities covered include agriculture, communications, education, health, training, cottage industries and subsidiary employment, housing and social welfare. With the object of dissociating the project from the central government machinery as much as possible it was not put in charge of the district officers, with their executive, police and tax-collecting functions, but under a project executive officer for each area of about 500 villages with a population of about 200,000.

In the villages there is a functionary known as the Village Level Worker who is supposed to provide a commonsense answer to the majority of the questions arising in the various fields of village life or to know where to turn for expert guidance. So popular has the scheme become that the Indian Government, faced with limitations of finance and manpower, was forced to launch a less comprehensive scheme, now integrated with the original scheme, under the title National Extension Service. This has inevitably led to some administrative changes and an increase in the authority of functional officials, whose interest in achieving measurable results has apparently led to some undermining of the popular nature of the movement.

This paper led to an interesting discussion on the relative merits of concentrating resources on isolated, large-scale schemes such as those of river control and electricity generation, or of spreading them thinly over a wide area in the hope of achieving a more balanced improvement in economic and social conditions. The answer must partly depend on the physical and social conditions of the territory. It was pointed out, for instance, that village project schemes, involving an evolutionary approach, can only be built upon suitable traditional ways of living. In the Indian villages, crops have been grown for centuries with elaborate systems of conserving water and numerous small-scale irrigation schemes in a pattern which takes advantage of the two-season type of climate. These conditions are not fulfilled in East Africa, with its nomadic pattern of agriculture, over-grazing, inefficient land use and severe soil erosion, and here a more radical approach is needed. Nor are such schemes small, when considered in terms of the total resources employed, and it was suggested that they might involve the employment of far more " bureaucratic " officials to feed the information and the materials to the individual villages than centrally controlled large-scale schemes which might achieve better ultimate results by providing the means of raising cultivation methods and living standards.

A decision was taken to establish the Centre and a provisional committee of 32 members, representative of all the professions concerned and of a large number of countries, was set up.

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REGULATIONS FOR ELECTRICAL EQUIPMENT OF SHIPS

New Edition Authorised

The Council of the Institution of Electrical Engineers have authorised the preparation of a fourth edition of the " Regulations for the Electrical Equipment of Ships." This will supersede the existing third edition (which was published in 1939) as amended by the 1947 Supplement.

The work of preparation will shortly be undertaken by the Committee on Regulations for the Electrical Equipment of Ships, who will welcome comments or suggestions. These should be addressed to the secretary of the committee, Savoy-place, London, W.C.2, before January 1, 1956.

PERSONAL

VISCOUNT CHANDOS, D.S.O., M.C., has accepted the invitation of the Government of Northern Ireland to be the chairman of the Industrial Development Council set up to assist the Government to promote new industries and to reduce unemployment in Northern Ireland.

MR. H. W. BOSWORTH, at present chairman of Lancashire Dynamo Holdings Ltd., is to relinquish this position at the end of the present year but will retain his seat on the board and his connection with the associated companies. The chairmanship will be taken up by SIR PERCY H. MILLS, Bt., K.B.E. MR. S. F. STEWARD, C.B.E. M.I.Prod.E., has been appointed managing director of the company.

MR. G. M. BINNIE, M.A. (Cantab.), M.I.C.E., has accepted the invitation to be President of the Junior Institution of Engineers, Pepys House, 14 Rochester-row, London, S.W.1, for 1955-56.

PROFESSOR ARNOLD TUSTIN, M.Sc., M.I.E.E., has been appointed a member of the British Transport Commission's research advisory council. The council includes up to eight outside scientists and its function is to advise the Commission on the organisation and application of research.

The Lord President of the Council has appointed PROFESSOR P. M. S. BLACKETT, M.A., F.R.S., Professor of Physics, Imperial College of Science and Technology, and MR. H. DOUGLASS, general secretary of the Iron and Steel Trades Confederation, to be members of the Advisory Council for Scientific and Industrial Research from October 1. MR. J. CRAWFORD, J.P., PROFESSOR T. R. C. FOX, M.I.Mech.E., M.I.Chem.E., and SIR GEORGE THOMSON, D.Sc., F.R.S., retired from the Council on September 30, on completion of their terms of office.

MR. G. A. PLUMMER, M.I.Mech.E., M.I.Mar.E., has been appointed to the main board of John Thompson Ltd., Ettingshall, Wolverhampton. He is, and will continue as, a director and chief engineer of John Thompson Water Tube Boilers Ltd., Wolverhampton, one of the group of companies controlled by John Thompson Ltd. In recent years Mr. Plummer has been concerned with the company's nuclear-power projects and will continue in this capacity.

MR. A. W. GOSLING, B.Sc. (Eng.), A.M.I.Mech.E., has joined the Diesel-engine division of Armstrong Siddeley Motors Ltd., Coventry, as chief engineer.

MR. H. SAVAGE, M.B.E., B.Sc. (Eng.), M.I.C.E., has been appointed assistant civil engineer (modernisation), British Railways, Western Region, Paddington.

MR. E. R. WILKINSON, M.I.Mech.E., M.I.E.E., commercial manager, Central Electricity Authority, is relinquishing his post at the end of the year to join the boards of Power Securities Corporation Ltd., and Balfour Beatty & Co. Ltd.

MR. MAURICE TATTERSFIELD, director and general manager of the Brush Electrical Engineering Co. Ltd., is to be managing director of the company from October 10.

MAJOR CYRIL DENNIS, who entered the petroleum industry in 1920 and has served since then with W. B. Dick & Co. Ltd., now the principal subsidiary company of C. C. Wakefield & Co. Ltd., 46 Grosvenor-street, London, W.1, is retiring from his executive duties at the end of the year. He will continue, however, as an ordinary director of W. B. Dick & Co.

MR. C. E. BLUNT and MR. J. A. GRACE have been elected to the board of directors of Folland Aircraft Ltd., makers of the Gnat light jet fighter, Hamble, Southampton.

MR. S. G. W. CAMBERS, hitherto general manager of F. H. (Newcastle) Ltd., Pottery-lane, Newcastle-upon-Tyne, 1, has been elected to the board as managing director.

MR. J. DENT, B.Sc., A.M.I.Mech.E., has been appointed assistant chief engineer, guided weapons, at Short Brothers and Harland Ltd.

MR. L. C. HAWKINS, a member of the London Transport Executive, with the agreement of the British Transport Commission, has been appointed chairman of the Transport Commission which is being set up to advise on the development of the passenger-transport system in Singapore. Mr. Hawkins was formely comptroller of the London Passenger Transport Board.

MR. G. D. MOLE, B.Sc., joined the staff of Smiths Aircraft Instruments Ltd., Cricklewood, London, N.W.2, as a project engineer (engines) on October 3. He has come to Smiths from Rolls-Royce Ltd., where he has been personal assistant to the chief executive.

MR. A. GORDON FOSTER has joined the staff of the Furniture Development Council as head of the technical information service and library at 2-4 Dalmeny-avenue, London, N.7.

MR. D. B. CLARK, A.M.I.E.E., has been made assistant manager, Glasgow office, of the Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester, 17. MR. A. L. FULLER, A.C.G.I., A.M.I.E.E., has been appointed assistant manager, London office.

MR. D. C. ALTMAN has been appointed sales manager, industries group, Allis Chalmers Great Britain Ltd., Salisbury House, London Wall, E.C.2.

DR. F. R. ERSKINE CROSSLEY, M.A. (Cantab.), Associate Professor of Mechanical Engineering, Yale University, New Haven, Connecticut, U.S.A., has been awarded a grant from the National Science Foundation, Washington, District of Columbia, amounting to 12,000 dols, for research in non-linear mechanical vibration.

Seven engineers and scientists have been admitted to honorary membership of the American Society of Mechanical Engineers, 29 West 39th-street, New York 18, U.S.A. They are MR. J. B. ARMITAGE (Kearney and Trecker Corporation, Milwaukee); MR. J. H. DOOLITTLE (Shell Oil Co., New York); MR. S. B. EARLE (Clemson College, South Carolina); MR. S. T. HOYT (Castle and Cooke Ltd., Honolulu); MR. C. G. A. ROSEN (Caterpillar Tractor Co., Peoria, Illinois); MR. P. SPORN (American Gas and Electric Co., New York); and MR. C. E. WILLIAMS (Battelle Memorial Institute, Columbus, Ohio).

MR. T. P. BERINGTON, who joined Monsanto Chemicals Ltd., 8 Waterloo-place, London, S.W.1, in May, 1929, and was appointed to the board of directors in March, 1930, has been elected vice-chairman of the company.

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COMMERCIAL

CRAWFORD & CO. (TOTTENHAM), LTD., have changed their name to CRAWFORD COLLETS LTD., Tower Hill Works, Witney, Oxfordshire.

Arrangements have been made for the two Sunderland works of the RICHARDSONS WESTGARTH GROUP, the NORTH EASTERN MARINE ENGINEERING CO. LTD., and GEORGE CLARK (SUNDERLAND) LTD., to be run under the same management. The assets and all obligations at South Dock and Southwick are to be merged in the George Clark Co. and the name of that company is to be changed to GEORGE CLARK AND NORTH EASTERN MARINE (SUNDERLAND) LTD. MR. W. R. JONES takes over the managing directorships of the North Eastern Marine business at South Dock in addition to that of the George Clark business at Southwick. MR. A. H. W. DAWSON continues to be director and resident manager at South Dock. The North Eastern Marine business at Wallsend is not affected by the above arrangement.

The address of the ASSOCIATION OF BUILDING TECHNICIANS is now 1 Ashley-place, London, S.W.1. (telephone: VICtoria 0447–8)

CLARKSON (ENGINEERS) LTD., Nuneaton, have opened a new office and stockroom at 17 Cumberland-street, Bristol, 2. (Telephone: Bristol 2—8464) to handle the firm's business in the West of England and South Wales.

An agreement recently made between ROBERTSON THAIN LTD., Ellesmere Port, Wirral, Cheshire, FRANK SEGNER & CO. LTD., Manchester, and BUSH, BEACH AND GENT LTD., London, permits the two last-named companies to market those grades of " Stypol " polyester resins which are used for general laminating purposes. " Stypol " HLT and those resins employed for potting and casting electronic equipment, however, will still be sold exclusively by Robertson Thain Ltd.

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CONTRACTS

Rolling Mill. A contract valued at nearly £300,000 has been received by DAVY AND UNITED ENGINEERING CO. LTD., Sheffield, to build a new hot-strip rolling mill for Surahammars Bruks A.B., Surahammar, Sweden. The new mill, a 60 in. wide four-high reversing unit which will need an 8,000 h.p. motor to drive it, is being designed specially for the hot rolling of alloy-steel strip. It will operate in conjunction with an existing roughing mill and new coiling furnaces in which the strip will be maintained at rolling heat.

Heavy-Duty Motor Vehicles. An order for 50 eight-wheeled Octopus heavy-duty motor vehicles, driven by 150 h.p. Diesel engines, has been placed by Tozers Transport Ltd., with LEYLAND MOTORS LTD., Leyland, Lancashire. A previous order called for 30 forward-controlled Comet vehicles, while the firm are now taking delivery of 50 similar Comet vehicles.

Obituary

MR. THORNYCROFT DONALDSON

Design of Torpedo Boat Destroyers

All those connected with marine engineering will learn with regret of the death of Mr. Thornycroft Donaldson, which occurred at Lymington, Hampshire, on Saturday, September 24, at the age of 82. In collaboration with the late Sir John Thornycroft he assisted at the birth of what was then a new type of warship—the torpedo boat destroyer—which marked a departure from previous marine engineering practice owing to the high power/weight ratio that could be embodied in it.

Thornycroft Donaldson was born at Chiswick in December, 1872, and was educated at Temple Grove School, Charterhouse and Trinity College, Cambridge, where he obtained his trial cap for rowing. He subsequently studied at the Central Technical College, London, under Professor W. E. Ayrton; and then joined the firm of Thornycroft, of which his father was a partner and with which he himself was associated during the rest of his working life. At the time of his father's death in 1899, he was already assistant engineering manager, at the early age of 27, and on the formation of John I. Thornycroft and Company, Limited, two years later, became technical director.

At that time the works of the firm was at Chiswick, where much research work had been carried out by Sir John Thornycroft and Mr. Donaldson senior since the early seventies. The valuable data thus collected enabled Thornycroft Donaldson to design and construct a combination of water tube boiler and high-speed reciprocating engine, the performance of which was only surpassed by the steam turbine.

When the works was moved from Chiswick to Woolston, Southampton, Donaldson became responsible for all machinery design at a time when the change-over was taking place from reciprocating engines to turbines, and supported by great technical knowledge and infinite patience he was able to overcome the inevitable complications of this important conversion. At a later stage he passed through a similar experience when the move to replace steam by Diesel plant occurred. His conviction that the basic principles of engineering do not change enabled him successfully to carry out the duties of the post of Director and General Manager of the works and shipyard at Woolston to which he was appointed in 1921. He retired from active work in 1953.

Mr. Donaldson was elected an Associate Member of the Institution of Civil Engineers in 1898 and was transferred to the class of Members in 1913. He was awarded a Telford Premium for a paper on "Stress in Bent Pipes," in 1899. He became a Member of the Institution of Mechanical Engineers in 1929.

The late Mr. Thornycroft Donaldson.

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MR. ARTHUR WATSON

Management of Iron Production

It is with regret that we record the death of Mr. Arthur Watson, which occurred suddenly at Stanton on September 22, during the opening ceremony of a coke-oven plant extension with which he had been closely connected. Mr. Watson, who was in his 63rd year was, assistant managing director of the Stanton Ironworks Company Limited, near Nottingham.

Mr. Watson was born in Glasgow and educated at Glasgow High School and the Royal Technical College. He commenced his business career with a firm of coalmasters and later transferred to the Summerlee Iron Company Limited. At the outbreak of the war of 1914–18, he joined the ranks of the Highland Light Infantry and in 1915, obtained a commission in the Royal Artillery. He was demobilised in June, 1919, with the rank of Captain, and returned to his previous employment. In October, 1919, however, Mr. Watson joined the staff of the Stanton Company and was posted to the iron-pipe department. From this he was appointed personal assistant to the commercial manager and later took charge of the foundry sales department. In 1933, he was made manager of the iron-pipe department and in 1939, commercial manager of the cast-iron department. Final promotion to assistant managing director came in July, 1940.

Mr. Watson had been actively connected with many trade associations and, at the time of his death, was chairman of the Cast Iron Segment Association and of the Cast Iron Pipe Association, and a member of the executive committees of the Joint Iron Council, the Foundry Pig Iron Producers' Association and other bodies. He was also a director of the Holwell Iron Company Limited, Cochranes (Middlesbrough) Foundry Limited, the Kettering Iron and Coal Company Limited, the New Cransley Iron and Steel Company Limited, aud other firms. He was a Liveryman of the Worshipful Company of Founders.

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SAFE TRANSIT OF SCIENTIFIC INSTRUMENTS

Research laboratories engaged on scientific measurements frequently require to transfer their instruments to laboratories in other countries for comparison with instruments of a similar character, and if these delicate mechanisms are to reach their destinations undamaged it is essential that they be handled with special care by customs officials in both the exporting and the importing countries.

Accordingly, an internationally-recognised scheme, originated under Unesco auspices, was brought into operation in August, 1954, and this provides that instruments passing between approved laboratories may bear a special label to indicate their fragile nature. Packages of instruments so designated are normally examined only at the laboratories concerned and are passed through the customs depots without further inspection, thus minimising the possibilities of damage and delay. The scheme is at present operated by 22 countries, including Britain, Australia, India, Pakistan and the Union of South Africa. The United States of America, Canada and 13 other countries have expressed their interest. The procedure is simple. The Governments of countries desiring to participate in the scheme are required to send to the Director-General of Unesco, in Paris, the names and addresses of the laboratories they desire to benefit, together with particulars of the methods, including customs provisions, by which their officials propose to work the scheme.

THE SITING OF NUCLEAR POWER STATIONS

Lord Citrine on Technical Requirements

At a Press conference held on the occasion of the publication of the seventh annual report of the British Electricity Authority, to which reference was made on page 441 and page 447 of our last issue, Lord Citrine gave some interesting information regarding the siting and other matters connected with the construction of the 12 nuclear power stations scheduled in the recent Government White Paper.

It was hoped, he said, to bring these stations, which would provide from 1,500 to 2,000 MW, into commission by 1965. Following the publication of the White Paper, representations had been received from local authorities and a number of interested persons that these stations should be sited in their areas. Siting had, however, to be considered from the broad national standpoint, in the forefront of which was the question of safety.

It was true, he continued, that the natural-uranium carbon-moderated gas-cooled reactors (Pippa type reactors) which would be used at these stations were inherently safe in operation. Furthermore, comprehensive safety precautions would be incorporated in the design of the reactors and the associated plant to ensure the effective containment of radioactive materials at all times. Nevertheless, it was proposed, as was foreshadowed in the White Paper, to site the early stations well away from urban areas. It might be that when nuclear generation became an everyday affair these precautions would appear extravagant, but it was felt to be the right policy for the early stations.

The technical requirements for nuclear sites were, added Lord Citrine, quite complex, but three factors deserved mention. Since the cost of uranium fuel was virtually independent of location, the nuclear stations would show the best economy in the national system of electricity generation if they were sited where normal fuels were expensive. This meant away from the coalfields which were producing the biggest quantities of the low-grade coals used in ordinary power stations, that is the Midlands, Yorkshire, the North East Coast and South Scotland.

Economy was also helped if the stations could be near the areas of heavy electrical demand. The cost of transmission was then low and the stations could be run continuously so as to extract the maximum output of electricity from the heavy capital investment in the nuclear plant.

These broad considerations pointed to the south of England, and in particular to the Severn Estuary and the coast of Essex as the most suitable areas for the first stations. Various sites had been investigated and the work of assessment was nearing completion.

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LARGE STEEL CASTING

A steel casting poured in Sheffield 11 days ago (on September 26) is still cooling and will require another 20-odd days before it can be raised from the casting pit for heat treatment, fettling and machining. Poured at the Grimesthorpe Foundry of the English Steel Corporation Limited, Sheffield, the casting, a 166-ton forging-press entablature, measures 28 ft. 6 in. in length, 14 ft. 2 in. in height and 8 ft. 6 in. in width. During the 25-minute casting operation and the subsequent feeding, 225 tons of steel were used. The bulk of it, 194 tons, came from three ladles teeming simultaneously, while the remainder was added to ensure that the casting is sound. To produce this quantity of steel, three open-hearth furnaces and three electric-arc furnaces were required. The pattern used was in ten sections. It had taken three months to build and needed three journeys to bring it from the maker's works, at Batley, to Sheffield.

Institute of Metals Autumn Meeting (*continued from page* 475)

TRANSFORMATIONS IN COPPER ALLOYS

Continuing our report of the annual autumn meeting of the Institute of Metals, held in Buxton, from Monday, September 19, to Friday, September 23, we now deal with the proceedings of the afternoon of the first day, when two simultaneous technical sessions, "A" and "B", were held.

The chair at session "A" was occupied by Professor A. G. Quarrell and the four papers on the agenda, on the general theme of "Transformations in Copper Alloys," were presented by Dr. J. W. Christian acting as *rapporteur*.

The first paper was by Dr. R. Haynes, of Imperial Chemical Industries, Limited, Metals Division, Birmingham, and described work carried out in the Department of Metallurgy, University of Sheffield. The paper dealt with "Isothermal Transformations of Hypo-Eutectoid Aluminium Bronzes." The author stated that a binary hypo-eutectoid copper-aluminium alloy and similar alloys containing small amounts of nickel had been transformed isothermally in the range 350 deg. to 560 deg. C., and the results had been plotted as time-temperature-transformation diagrams. It had been found that nickel had little effect on the rates of transformation, but 3 per cent. nickel resulted in the formation of a double "knee" in the curve representing the start of the eutectoid reaction.

The second paper was concerned with "The Bainitic Transformation of the Beta Phase in Copper-Zinc Alloys," and was by Mr. R. D. Garwood, lecturer in metallurgy, University College, Cardiff. The author stated that the isothermal decomposition of the metastable β phase had been studied in a copper-zinc alloy, containing 41·3 per cent. zinc, over the temperature range 170 deg. to 470 deg. C. The plate-like particles precipitated below approximately 350 deg. C. developed by a process of slow, coherent growth, causing surface upheavals analogous to those occurring in the formation of bainite in iron-carbon alloys. Above 350 deg. C., simultaneous decomposition occurred by an alternative process which gave particles of irregular shape.

The third paper was upon the subject of "Isothermal Transformations of Eutectoid Aluminium Bronzes," and the author was again Dr. R. Haynes. In the course of his paper, he stated that he had redetermined the eutectoid temperature for the β phase of the copper-aluminium system as 565 deg. $\pm$ 2 deg. C., and had established the eutectoid composition as 11·96 $\pm$ 0·05 per cent. of aluminium. The addition of nickel to binary alloys raised the eutectoid temperature, and the eutectoid "gutter" rose to the four-phase plane at 605 deg. $\pm$ 2 deg. C. associated with the phases α, β, γ_2, and NiAl.

A binary eutectoid alloy and similar alloys containing small amounts of nickel had been transformed isothermally in the range 350 deg. to 560 deg. C., and the results plotted as time-temperature-transformation diagrams. Nickel had little effect on the rates of transformation, but the alloy containing 3 per cent. of nickel exhibited a double "knee" in the curve representing the start of the eutectoid reaction.

The fourth and last paper was entitled "Some Observations on Isothermal Transformations of Eutectoid Aluminium Bronzes below their Ms Temperatures." It was also by Dr. R. Haynes, who stated that he had studied the microstructural changes occurring during transformations of three aluminium bronzes below their respective Ms temperatures (these being the temperatures indicating the commencement of a martensitic-type transformation). The results suggested that the isothermal formation of martensite occurred and that both martensite and the phase from which it formed might transform to eutectoid. Small additions of nickel to the binary alloys depressed the Ms temperatures and increased the rates of transformation.

CORROSION OF ALUMINIUM ALLOYS

The chair at session "B" on Monday afternoon was occupied by Dr. A. Edwards and the theme of the first two papers, presented by Mr. E. A. G. Liddiard as *rapporteur*, and subsequently discussed together, was "Corrosion of Aluminium Alloys." The first paper was entitled "Corrosion-Fatigue Properties of an Aluminium-Magnesium-Silicon Alloy in the Unprotected, Anodised and Painted Conditions." The authors, Dr. N. P. Inglis and Mr. E. C. Larke, of Imperial Chemical Industries, Limited, Metals Division, Birmingham, stated that the endurance strength of a fully heat-treated aluminium-magnesium silicide alloy of the H10 type had been determined in air and when subject to the action of distilled water, ordinary tap waters, and a 3 per cent. sodium chloride solution. The endurance strength of the alloy was much reduced in the presence of these liquids, the corrosion-fatigue strength in Birmingham or London tap water being about half that in air, while the corrosion-fatigue strength in the salt solution was only 25 per cent. of the fatigue strength in air.

Anodising afforded an appreciable measure of protection against corrosion-fatigue effects, although the fatigue strength, in air, of the anodised metal was rather lower than that of the unprotected metal. Painting in accordance with a carefully specified schedule (including a chromating treatment to produce paint-holding properties, coating with a red oxide-chromate priming paint and finally spraying with an alkyd finishing paint) gave extremely effective protection even under the most severe corrosion-fatigue conditions. The fatigue strength of the painted material in the salt solution was rather better than that of the unprotected material in air.

The second paper was by Dr. F. A. Champion, of the Research Laboratories of the British Aluminium Company, Limited, Gerrards Cross, Buckinghamshire, and dealt with "The Interactions of Static Stress and Corrosion with Aluminium Alloys." The author stated that stress-corrosion failures in service were very rare, and, in fact, far more stress-corrosion had been observed in the laboratory than in service, partly because the laboratory results had served to minimise the risk of stress-corrosion in service, and partly because laboratory tests had included conditions more severe than those experienced in service. The latter factor was evidently advantageous in providing a safety margin, but care must be taken to ensure that excessive safety margins did not place unnecessary restrictions on the alloys available to the engineer.

Thicker metal was advantageous when it reduced the stress per unit area and, in general, much could be done at the design stage to minimise corrosion risks. Rolled-on cladding offered the maximum protection, and sprayed-metal coatings appeared to be equally effective. Painting had been effective in some applications, especially when preceded by anodising and supplemented, where necessary, by suitable jointing compounds.

DISCUSSION

Dr. U. R. Evans in opening the discussion said that Dr. Champion would like to restrict the term "stress corrosion" to cases in which corrosion and stress, operating together, produced more damage than when they operated separately. If this restriction were accepted, it should not blind investigators to cases in which ordinary intergranular corrosion, acting without high stress but over long periods, weakened the material so that when, later, a stress, which at the outset could have been withstood, were momentarily applied, fracture occurred. Such failure would be ascribed, rightly, to mechanical fracture, and the part played by corrosion might never be brought to light.

Moreover, there was layer corrosion, which had caused some anxiety in recent years. This, presumably, was excluded from Dr. Champion's "select company" of genuine stress-corrosion failures, since the stress was mainly generated by the corrosion itself. If once attack started along lamellae, either at the sheared end of a plate, or at a place where the surface layers had been cut away for some legitimate purpose, the expansional forces due to the voluminous character of the corrosion products, would lever up the unchanged aluminium layers and open up a path for the further advance of the corrosion.

If it were a fact that stress-corrosion and allied phenomena were rare in service, this must be attributed to the vigilance of the inspectorate and maintenance staff and to the restraint of the designer, who deliberately refrained from using materials possessing the mechanical properties which he would like. However short might be the list of material definitely convicted of corrosion cracking (and continued research might add to that list), the situation must be regarded as unsatisfactory while the list contained some of the strongest and most attractive light alloys.

It was often stated that cladding and spraying provided the remedy. Even when not cut away, cladding did not always protect the face of the underlying metal, notably when clad copper alloy was exposed to heat, permitting diffusion of copper outwards along grain boundaries which became cathodic towards the interior. Corrosion of the cladding thus followed.

Stress corrosion and layer corrosion generally resulted from under-ageing and it would seem that more attention should be given to this matter in the otherwise excellent literature on heat treatment provided by the aluminium industry. Furthermore, it had been stated by American investigators that the increasing size of pieces requiring heat-treatment was making it increasingly difficult to preserve correct conditions everywhere.

Dr. T. P. Hoar referred to the finding by Dr. N. P. Inglis and Mr. E. C. Larke that the fatigue strength, in air, of their anodised alloy was rather lower than that of the unprotected metal and suggested that this might be due to a small "nick" in the metal below the anodised film at the junction of a grain boundary.

Dr. H. Sutton, pleaded for more work to be done on specimens under dynamic stressing. In aircraft, metals were rarely used under static stresses. Bolts, for instance, were exposed to a good deal of vibration and pulsating stresses. He was glad that Dr. Inglis and Mr. Larke had used different kinds of water in their corrosion tests as this was of interest and importance to aircraft firms and administrations.

In his reply Dr. Inglis said that the proprietary chromating treatment given to their specimens prior to painting was that normally employed by persons who painted their alloys. He added that their corrosion-fatigue tests had indicated that their painted specimens had behaved extremely well but that the tests had lasted for about a fortnight only. Since then the results of tests occupying 20 weeks and even longer had shown that the paint had continued to give effective protection. Their finding that anodising actually reduced somewhat the fatigue strength in air was supported by microscopic examination, which revealed small surface defects in the anodised layer; these presumably acted as stress-raisers under the subsequently applied alternating-stress conditions. In the course of his reply, Dr. Champion, stated with regard to Dr. U. R. Evans's point on the diffusion and corrosion of cladding, that this depended on the thickness of the cladding. With the commercial thicknesses of cladding commonly used in engineering practice this danger was relatively small.

To be continued

Book Reviews

TRANSISTORS

Transistors and Other Crystal Valves. By T. R. SCOTT. *Macdonald and Evans, Limited, 8 John-street, Bedford-row, London, W.C.*1. (45*s.*)

It may be unusual to begin a review by referring to the bibliography, but in the present book it plays a particularly important part and is very extensive, containing 277 references. These represent only a fraction of the published work on the subject, which in turn represents only a fraction of the work carried out, mostly since the war, on semi-conductors and their application in transistors and related devices. Not only the newcomer to the field, but also those with considerable experience are apt to be bewildered by the wealth of material available and by the way much of it is scattered among a wide variety of scientific and technical publications. If this book provided no more than a critical review of published material, it would be of considerable value. It does this and much more, for the author sets out to explain, with a minimum of mathematics and in terms intelligible to the non-specialist, the properties of semi-conductors, how these are utilised in transistors and how transistors themselves are used.

The book begins with an historical introduction which shows that crystal valves are by no means new. The crystal detector has been known for many years and the author quotes a reference to asymmetric conduction in solids as early as 1835. It appears that the first transistor was made to oscillate and amplify in 1924. The next chapter indicates why there was very little progress until quite recently. Consistent transistor action depends upon the presence of minute but controlled amounts of imperfections in the otherwise pure monocrystalline semi-conductor (usually germanium or silicon at present) and this is achieved only by the most refined techniques.

The following chapter describes how rectification occurs at a junction within a crystal of regions containing different types of impurity, and how a pair of such junctions closely spaced in the crystal give amplification by transistor action. This leads to a description of junction transistors, now in production, and their properties. The point-contact rectifier and point-contact transistors are similarly described, and the author takes a more hopeful view of the future of the point-contact transistor than appears to prevail in the United States. He makes an interesting and perhaps controversial statement on page 112 in saying that point-contact transistors appear to be cheaper to manufacture than junction transistors. This conflicts with what is widely believed, but the author is in an almost unrivalled position to know.

The chapter on transistor circuits is perhaps the least satisfactory, for it amounts to little more than a précis of published papers, some now rather out of date, and the reader will not learn a great deal unless he turns up the more recent papers referred to. The author regards detailed discussion of transistor circuits as outside the scope of his book, but he might have given a clearer picture of where the advantages of using transistors lie.

The last two chapters deal with special high-frequency transistors (most of which are still at the theoretical stage or have been made only experimentally), and with the possibilities of semi-conductor materials other than germanium and silicon, these being considered in some detail.

There are two appendices, the first a brave attempt to explain in non-mathematical terms the quantum mechanics leading to the energy-band structure of semi-conductors, which is the basis of transistor action. This attempt succeeds better than most. The second appendix deals with the electrical testing of diodes, transistors and semi-conductor materials. There are a few faults, including the common one of using "*e*" as the symbol both for the electronic charge and for the base of Napierian logarithms. On page 48 this symbol appears in both guises in the same sentence. In places the author relies too much on his bibliography and here the text becomes little more than a list of references. This will be particularly exasperating to the reader without easy access to the literature. Nevertheless this is probably the most comprehensive and best balanced book on transistors which has so far appeared on either side of the Atlantic.

WAGES

National Wages Policy. By JAMES DRISCOLL. *The Bow Group, 30 Pall Mall, London, S.W.*1. (2*s.*)

The Bow Group consists of a number of young Conservative intellectuals who are trying to do for the Conservative Party what the Fabian Society has been doing for the Labour Party and its antecedents for three-quarters of a century. They have carried their emulation to the point of starting a series of spring lectures, similar to the traditional Fabian autumn lectures, and two of them have now been published in one pamphlet (the other is "The Audience of Politics," by George Engle). Mr. Driscoll, who was on the staff of the Department of Industrial Relations at Cardiff University, and a Conservative candidate in 1950, is to-day employed in the steel industry. His lecture is a very able statement of the problem of wages in a full employment economy, but some of his ideas would hardly be acceptable to the traditional Conservative voter. His conclusions, in fact, do not differ from those which might be expected from the more moderate Labour Party economists, such as Professors James Meade and Arthur Lewis.

Briefly, Mr. Driscoll belongs to the school of economists who hold that the Government can, and should, keep aggregate money demand in line with available resources, and so limit inflationary pressure almost entirely by monetary policy. That done, there should be little difficulty, given the present responsible attitude of the trade union leaders, in keeping wage increases, negotiated by the ordinary collective bargaining machinery, within reasonable bounds. In order, however, to reinforce monetary policy he suggests the creation of a well-staffed tripartite Wages Council, which would provide background information for all parties engaged in wage fixing and seek voluntary agreement on advice to be given on the direction and general rate of wage changes.

The most controversial part of these proposals is the rules which it is proposed should be developed to guide the Industrial Court and Arbitration Tribunals, particularly on the relationships between wages in different industries and for different degrees of skill. Mr. Driscoll proposes that these bodies should be instructed to publish the reasons for their wage decisions in all cases, and so build up a body of case law. This is not a new idea, but it fails to face the difficulty that there are no agreed standards by reference to which cases brought before Tribunals can be determined. At the present time the decisions which are given are compromises which it is hoped will strike a balance between the power on either side. Apart from the general request for restraint made in 1948, governments have fallen over backwards to proclaim the complete independence of the Tribunals, not only from interference with their judgments, but from guidance on the principles by which they should be determined. Consequently relative wages and salaries, as Professor Barbara Wootton has recently pointed out, conform to no pattern of economic law or social justice, but follow long-established social traditions and any decision to make changes in relative standards of remuneration hallowed by tradition must inevitably be based on a particular political philosophy.

It is inconceivable that any trade union would give up its full right to obtain the best possible conditions for its members while other forms of income, whether from professional work or from ownership of property, went uncontrolled. With some courage Mr. Driscoll recognises that a fall in the rate of return on capital. due to a squeeze on profits by higher wages, need not provoke a disastrous fall in investment and employment, because capitalists cannot withdraw their capital and will, over a period of time, become used to lower yields. He believes, however, that the trade unions may not wish to press the redistribution of income as between income from work and income from property any further at the present time. This may be wishful thinking, especially after the partial reversal of trends brought about by recent dividend increases and the consequent boom in share values.

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TRADE PUBLICATIONS

Copies of any of the following trade publications are obtainable from the addresses given, though distribution is sometimes restricted.

Fluorocarbons. EDISON SWAN ELECTRIC CO. LTD., 155 Charing Cross-road, London, W.C.2. Polytetrafluoroethylene (PTFE) and polymonochlorotrifluoroethylene (PCTFE); thermal, electrical, optical, chemical and mechanical properties; applications and available forms. Illustrated booklet.

Grinder Load Control Unit. MAGNETIC EQUIPMENT CO. LTD., Lake Works, Portchester, Hants. "Magco" control unit to ensure economical rate of feeding to grinder; feed rates from ¼ to 600 tons per hour; "Magco" bowl feeder to take small parts in bulk and deliver them in one or more single lines. Two illustrated leaflets.

Unit Heaters. MATTHEWS AND YATES LTD., Swinton, Manchester. Cyclone unit heater comprising low-pressure steam or hot-water gilled-tube radiator, electric motor and propeller fan; alternative electric-heater version available. Illustrated catalogue giving specification, performance tables, and dimensions.

Telephone Meter. AUTOMATIC TELEPHONE & ELECTRIC CO. LTD., Strowger Works, Liverpool, 7. Type 100 telephone meter, a call-counter or message register reading up to 9,999. Principles and details of construction, mounting arrangements, adjustments and tests. Illustrated booklet.

Stackers and Transporters. MATLING LTD., Park-lane, Fallings Park, Wolverhampton. Narrow and straddle stacking trucks for loads up to 3,000 lb., and stillage and pallet transporters for loads up to 4,000 lb. Petrol, battery or mains-driven models. Leaflets Nos. 102, 103 and 104.

Insulation Materials. NEWALLS INSULATION CO. LTD., Washington, Co. Durham. Paxmarine system for combined heat and sound insulation on board ship; assessment of problem and practical examples of solution; cold insulation; materials used and results. Two illustrated booklets.

Propeller Fans. MATTHEWS AND YATES LTD., Swinton, Manchester. Cyclone four-blade and six-blade electric propeller fans. Illustrated catalogue giving specifications, performance data, characteristic curves, particulars of driving motors, extras and accessories, and dimensions.

Engineering Capacity. NORTH EAST ENGINEERING BUREAU, 18 Ridley-place, Newcastle-upon-Tyne, 1. Leaflet giving particulars of the Bureau's free information service on plant and engineering capacity in Northumberland, Durham, Cumberland, Westmorland, and the North Riding of Yorkshire.

Brix Controller for Sugar Production. GEORGE KENT LTD., Luton, Bedfordshire. Measurement and control of Brix value of juice in production of sugar from cane or beet by RTS Brix Recorder/Controller. Illustrated leaflet.

Superchargers. WADE ENGINEERING LTD., Crow-hurst-road, Brighton, 6. Root's-type compressors and superchargers with capacities of from ¾ to 20 litres per rev. and pressures up to about 10 lb. per sq. in. Several models. Illustrated pamphlet.

Milling Cutters. FIRTH BROWN TOOLS LTD., Carlisle-street East, Sheffield, 4. "Zeelock" serrated blade cutters with adjustable blades of high-speed steel. Cutters from 4 to 10 in. in diameter. Descriptive list No. 199/2.

Pneumatic Tools. B. E. N. PATENTS LTD., High Wycombe, Buckinghamshire. Pneumatic tools for drilling, scaling, scraping, chipping, cutting and grinding. Catalogue C.B. 120.

POWER REACTOR PROJECTS THROUGHOUT THE WORLD

A COMPARATIVE SURVEY OF SCHEMES DESCRIBED AT GENEVA

By G. W. K. Ford, M.B.E., M.A. (CANTAB.), A.M.I.MECH.E.*

So much information has recently been revealed on the subject of nuclear reactors that to assimilate even a part of it would be a major task. Nevertheless, few can doubt the importance to world and national economies of knowing which reactor schemes offer the best prospect for the efficient production of electric power, and it is with this in mind that we are publishing the following article. It gives details in condensed and systematic form of all power reactor plans, projects and proposals discussed at the Geneva Conference, and makes extensive use of tables and associated schematic diagrams. Conference papers are referred to by means of the official code which employs the letter P followed by a number, as P490. Some reactors will have been covered at greater length in earlier issues of ENGINEERING, *but the present article is comparative and analytical rather than descriptive. Since much of the data given was not available before the Geneva Conference it is probably the most comprehensive treatment of the subject so far published.*

POWER NEEDS AND FUEL SUPPLIES

The object of this article is to make a comparative review of the leading engineering characteristics of the power reactor proposals, both in being and planned, which were presented at the Geneva Conference. A few schemes which were not described in detail at the Conference have been referred to and included in the tables because of their comparative or historic interest.

An attempt has been made to bring out in addition their relative economics since this is a matter of considerable significance, but it is important to realise the limitations of such comparisons. First, it should be appreciated that the current reactor programmes of the only five countries at present engaged in nuclear power production enterprises have rather different motivations and objectives.

Britain faces an imminent rise in fuel costs because coal production is almost static with ever-increasing prices, and fuel imports are necessarily dear. Therefore there is an economic incentive to build nuclear power plants immediately, and this is indeed being undertaken. The cost of power from these early plants is expected to be of the same order as that from coal-burning stations because of the relatively high price of coal in Britain, and they should thus become valuable additions to the existing power sources. It is generally considered that the rising costs of fossil fuels coupled with the usual fall in capital cost to be expected in new types of engineering enterprise will quite rapidly make the nuclear stations competitive. The complicated economics underlying the selling price of the plutonium by-product also considerably affect the economics of these natural-uranium burning power stations.

The United States do not have the same immediate need for domestic nuclear power production, although they clearly recognise that in a few decades they, too, will require nuclear power to keep pace with the increasing population, the rising use of power per head of population, and the depletion and consequent eventual rising cost of fossil fuel reserves. This breathing-space they intend to use for large-scale experiments in nuclear power production technology.

In spite of the fact that the United States is nominally only engaging upon a power demonstration programme of an experimental nature, if all the schemes now in the planning stage are implemented the United States will have, by 1965, two or three times the total nuclear power capacity of the United Kingdom. This would not, of course, represent such a large fraction of the total capacity as will have been achieved in Britain by that date.

It is this deliberate intention to carry out a widely varied and very large-scale nuclear power experimental programme which led to the presentation of so many papers and the display of such a diversity of advanced nuclear engineering techniques by the United States at Geneva. It is to be recognised, of course, that an important contribution to this state of affairs has been made by the developments leading up to military applications such as the Nautilus and Sea Wolf power plants and the aircraft propulsion programmes.

The U.S.S.R. nuclear power requirements would appear to be somewhere between those of America and of Britain. The experimental power reactor described is not claimed to be an economic proposition, but it seems that the U.S.S.R. is now proceeding with a nuclear power station construction plan. France is now experimenting with nuclear power production, but her nuclear power needs do not seem to be as pressing as those of Britain and the U.S.S.R.

Canada is about to enter a period when hydro-electric power will no longer suffice, particularly in certain industrialised areas, and foresees a real demand for nuclear power, probably earlier than that forecast for the United States.

CAPITAL AND DEVELOPMENT COSTS

Besides these direct effects of power needs upon the power reactor programmes, the following indirect effects and additional considerations must be taken into account when making comparisons.

(*a*) Some of the plants are definitely experimental in their objectives, although of full-scale power-plant size, and often include large capital charges appropriate to their experimental nature, e.g., the containment buildings for the pressurised-water reactor (PWR) at Shippingport, which may well turn out to be merely a high insurance premium peculiar to an experimental plant; and large development costs may often be hidden in the capital costs tabulated, e.g., 45 million dols. development costs for the PWR.

(*b*) Capital costs may be very different in different countries and be assessed in different ways, and interest and depreciation rates assumed may differ considerably. Since the cost of power delivered may be made up of roughly two thirds capital charges (c.f. one third for thermal stations) this is clearly a very important factor.

(*c*) The costs of natural and enriched uranium will vary from country to country. The costs shown in Table I for American reactors assume pure fissile material to cost 30 dols. per gram. The British power costs assume plutonium sold at 33 dols per gm. (P390) and natural uranium to cost 55 dols. per kg. compared with usually assumed costs of 40 dols. per kg. in U.S.A. and 44 dols. per kg. in Canada. Many of the American papers presented also show the effect upon power costs of the lower price of 15 dols. per gm. of fissile material. These cases have been excluded from this review, although this order of price is expected to be attained eventually in both Britain and the U.S.

The reactor schemes described in detail during the Conference sessions did not contain all the active nuclear power proposals in existence. Propulsion units were not discussed at all, nor the package reactor propositions. Nevertheless, package reactors may become in commercial demand in some areas of the world, and the American full-scale nuclear engineering experiments completed to date do in fact fall within the region of the package reactor power requirements, i.e., the 1 to 10 MW (electric) region. The APPR (Army Package Power Reactor) is included in Table II (item 9) for comparison.

Propulsion units do not, at present, appear to be commercially attractive even for ships. Aircraft propulsion is only of military interest at the moment, and the railway locomotive looks to be an unlikely application on both economic and safety grounds. The Nautilus power plant has been included in the table (item 7), however, because it constitutes a notable historic and technological landmark in nuclear power production, though quite uncompetitive as a commercial ship propulsion unit as built.

THREE MAIN CLASSES OF REACTOR

Technically, the reactors described fall into three main classes as follow. (A) Gas-cooled. (B) Water-cooled, including (i) non-boiling pressurised water, and (ii) boiling water. Schemes discussed in both classes (i) and (ii) employ either heavy water (D_2O) or light water (H_2O), and include both heterogeneous (solid fuel elements only in types described) and homogeneous (aqueous solution or suspension) examples. (C) Liquid-metal cooled, using (i) liquid metal as coolant only (usually sodium); (ii) liquid metal as fuel and heat carrier. There are also some interesting Netherlands proposals (class D) for using dry fuel powder as a circulating fuel and heat carrier, but these are in the feasibility study stage only.

Gas-Cooled Reactors.—Only Britain and France are engaged upon substantial gas-cooled power reactor programmes and only a limited amount of technical detail concerning design and performance has been made available. Gas-cooled reactors of the types described have the advantages of inherent nuclear stability in event of accidental coolant loss and negligible chemical reactivity between coolant and fuel during any ensuing overheating; the ability to operate on natural uranium; and quite high coolant outlet temperatures. They share with pressurised water the need for a considerable pressure-vessel container, in the case of the Calder Hall reactors determined by the limit of site-welding practicability (2 in. plate). A sizeable fraction of their gross output must be diverted to coolant circulation. The important fact is that the United Kingdom Atomic Energy Authority have shown that reactors of this type can now be built to be competitive with coal-burning stations as operated in this country.

Water-Cooled Reactors.—These fall into two main classes, non-boiling and boiling. Most of the design studies and practical proposals to date, which have been submitted to the Conference, fall into the non-boiling or pressurised water category. The main reasons for this are twofold. First, before the Argonne laboratory experiments it was generally considered that boiling within the reactor core would lead to unacceptable nuclear instability, and secondly that the attainable heat extraction rates with natural circulation boiling are lower than those attainable with pressurised water and forced circulation, being

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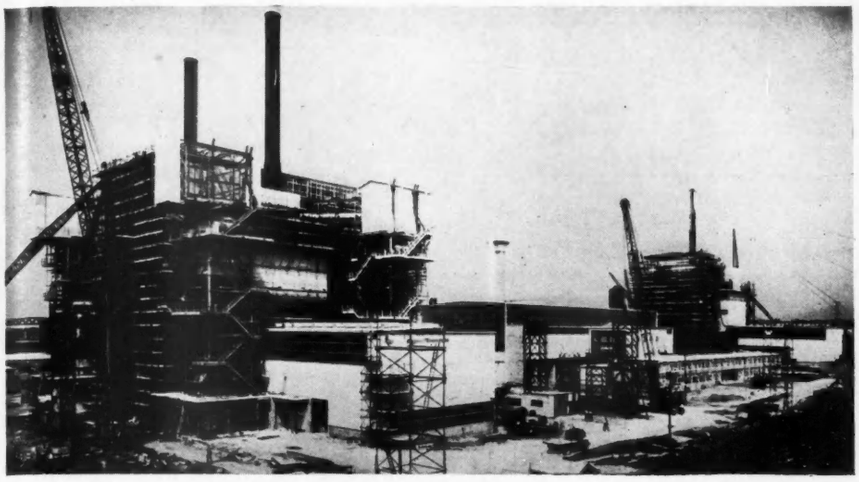
TABLE I.—COMPARISON OF COSTS.

No. in main table (Table II)	Power electric (MW)	Cost per kW inst. (dols.)	Interest on capital (per cent.)	Power cost, mills per kW hr., 80 per cent. load factor			
				Fixed charges (mills)	Fuel charges (mills)	Operation charges (mills)	Total (mills)
2 (CEANP)	75	340	6·6	3·7	4·4	0·7	8·8
— (RAPS (F))	100	—	—	—	—	—	~25
6 (HGPWR)	225	—	—	—	—	—	<7·0
9 (APPR)	1·0	—	—	27·8	*	25·5	53·3§
13 (D_2 PWR)	200	200 to 300	7·5 7·5	3·0 to 7·5	0·5 to 1·5	0·5 to 1·4	4·0 to 10·4
18 (BER III)	3·5	—	15	5·9	20·12	8·6	34·6
19 (EBWR)	4·5 9·0	890 445	15 15	19·1 11·4	6·6 6·2	8·5 4·2	34·2 21·8
21 (D_2BWR)	248	—	12·0	4·2	2·6†	0·9	7·7
21 (D_2 BWR)	62	—	12·0	7·7	4·6	2·3	14·6
21 (D_2 BWR)	62	—	12·0	7·7	5·3	2·3	15·3
(H_2 BWR)	62·5	—	12·0	6·8	8·6	2·3	17·7
(H_2 BWR)	61	—	12·0	7·2	5·2	2·3	16·8
24 (SGR)	75 100 125	300 265 <200	15 15 15	6·5 5·5 4·0	3·2 2·5 2·0	2·0 1·5 1·0	11·5 9·5 7·0
25 (LMFR)	210	238	16	5·4	1·7	6·7	7·8
27 (Fast)	150	300	10	4·28	2·81	1·0	8·09

Notes on Table I

CEANP = Central Electricity Authority Nuclear Power Stations.
RAPS (F) = Russian Atomic Power Stations (Future).
HGPWR = Hanford Graphite-Moderated Pressurised-Water Reactor (U.S.A.)
APPR = Army Packaged Power Reactor (U.S.A.)
D_2 PWR = Heavy-Water Moderated Pressurised-Water Reactor (Canada).
BER III = Boiling (light water) Experimental Reactor III (U.S.A.).
EBWR = Engine Cold Boiling (light) Water Reactor (U.S.A.).
D_2 BWR = Heavy-Water Moderated Boiling-Water Reactor (U.S.A.).
H_2 BWR = Light-Water Moderated Boiling-Water Reactor (U.S.A.).
SGR = Sodium Graphite Reactor (U.S.A.).
LMFR = Liquid-Metal Fuel Reactor (U-Bi) (U.S.A.).
Fast = Fast Fission Breeder Reactor (U.S.A.).
* = Fuel charges included in fixed and operation charges.
† = Includes all D_2O charges.
§ = For 60 per cent. load factor.



Reactors may be classified by the means of cooling employed. At Calder Hall, the coolant will be carbon dioxide gas and the moderator graphite. (Item 1 in Table II)

limited by the free water surface available for the escape of the steam. This is altered considerably by forced circulation through the boiling region, but this introduces other complications. The main disadvantages of either type are the need for pressure-vessel containment of the reactor core and the low steam temperatures available to the power plant. As will be seen from Table II, the types examined by designers range from natural uranium to pure fissile material for fuel, include heterogeneous (all solid fuel elements) and homogeneous (liquid fuel) arrangements and employ light water, heavy water or graphite for moderators, and either light or heavy water for coolant. Their pros and cons are examined in greater detail later.

Compared with the gas-cooled types, the consequences of pressure-vessel failure are more serious because of the large volume of active water which would flash into steam and later condense, possibly containing fission products from a water reaction with the fuel. This is, of course, enormously multiplied in the case of the homogeneous reactors where the fission products are dispersed, along with the fuel solute, in the water.

Liquid-Metal Cooled Types.—The main reasons for employing liquid-metal coolants in some reactor propositions are threefold.

(*a*) Higher operating temperatures are attainable than with water, while excellent heat-transfer properties are retained.

(*b*) Usable liquid metals have low vapour pressures so that no high-pressure containment is required.

(*c*) For fast fission reactors, gases are out of the question because of the fundamental compactness and consequently extremely high volumetric and surface heat ratings of reactors of this class, and water cannot be used because it softens the neutron spectrum on account of its moderating action upon the emitted neutrons.

SODIUM AND BISMUTH AS COOLANTS

For a variety of reasons, largely connected with neutron absorption or corrosion difficulties, or both, only two liquid metals have emerged which are of serious interest as reactor coolants, namely, sodium and bismuth. Sodium is satisfactorily contained in stainless steel or zirconium and has the additional bonus of being able to be pumped with fair efficiency by the electromagnetic pump. Bismuth has the special property of being able to dissolve sufficient fissile material to make possible a thermal neutron reactor the fuel of which is a pure liquid. It has not proved to be of special interest as a simple coolant in competition with sodium because of its high density, necessitating larger pumping powers and higher pressure differences, its relatively high melting point (271 deg. C. compared with 97 deg. C. for sodium) and its high cost. It is also more corrosive than sodium and the containment problem has not yet been completely solved. Therefore, apart from the solution reactor proposal (LMFR) all the liquid-metal cooled power reactors use sodium cooling. The low melting-point sodium-potassium alloy (NaK) is unsuitable for economic reactors because of the high neutron loss to the potassium.

Sodium used to cool a reactor becomes highly radioactive in use, and therefore all the primary circuits have to be shielded to protect the operating personnel. Because of this contained radioactivity and also its chemical reactivity, in particular its ability to burn in air and react with water, and the likelihood of widespread dispersion of its products of combustion (sodium peroxide dust), sodium presents a considerable potential radioactive hazard in event of a serious reactor accident, although ortunately it does not react chemically with the fuel. Therefore, as with water-cooled reactors, the policy in Britain and the United States is either to build such reactors at remote sites or to contain any possible accident product by housing the reactor in a gas-tight vessel, or both. It is interesting to note that the U.S.S.R. pressurised-water reactor is not so contained.

SAFETY PROBLEM

The accident hazard with the LMFR reactor is somewhat different. Although bismuth will burn in air, it is not so chemically reactive as sodium. However, when used as a fuel carrier it contains the fission products either in solution or suspension, or as gases, their concentration depending upon the rate of extraction in the continuous chemical processing system. Therefore there is a formidable safety problem with reactors of this type analogous to those of the water-solution reactors.

Having broadly reviewed the main types as distinguished by their coolants, and as further classification becomes increasingly difficult because of the wide variety of designs within each class, it is best now to consider the reactors listed in Table I in turn. Because by far the majority of papers giving economic assessments were from the U.S. all costs are quoted in dollars or mills. One dollar is approximately equivalent to £0·36, and one mill is one tenth of a cent or about 0·9*d*. The letters and figures give the table references.

A. Gas-Cooled Reactors

1. *The Calder Hall Reactors.*—The description of these reactors submitted to the Conference was mainly devoted to the numerous novel mechanical engineering problems which have been ingeniously and successfully solved during their design and construction. The most notable feature is the large size of the reactor pressure vessel; it is 40 ft. in diameter and 60 ft. high, is made of 2in. steel plate and operates at about 100 lb. per square inch internal pressure. The method of supporting the 1,000 tons cylinder of graphite so as to accommodate the differences in thermal expansion of the steel support and the graphite is of considerable interest. No details of the fuel elements were given. The economics are based on a fuel burn-up of 3,000 megawatt-days per tonne (MWd/tonne), but even assuming no sale value for the plutonium by-product, the cost of power sent out is as low as 9 mills per kilowatt-hour. (A view of the Calder Hall station, which is nearing completion, appears on the left.)

2. *The C.E.A. Power Station Reactors.*—No details of these reactors were given beyond an indication that their general design would be developed from the Calder Hall reactors and that their economics are expected to be better. The interesting possibility of using hydrogen as a coolant instead of carbon dioxide was mentioned. This would reduce the present pumping power of several thousand horsepower by a factor of 10.

CONCRETE PRESSURE VESSEL

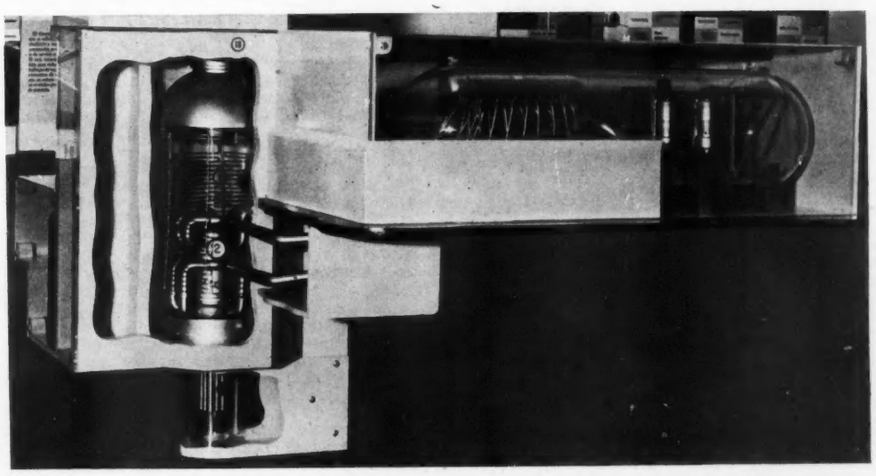
3. *The French Plutonium Producer G1.*—The electric power generation plant being installed at Marcoule in association with G1 is only a power recovery system, since the gross power generated (5·75 MW) is scarcely more than the air circulator power (about 5·6 MW). The primary object of the power plant is to provide an engineering exercise upon which to base full-scale nuclear power plant design. The cooling air is at approximately atmospheric pressure and leaves the reactor at the relatively cool temperature of 220 deg. C.

4. *The French Power Reactor G2.*—This reactor has been designed from the outset as a combined plutonium producer and electricity generator. It is of considerable interest in comparison with the Calder Hall units, being of similar power capacity. There are two major differences. First, the fuel channels are arranged horizontally in G2, and secondly the pile is split into two halves, the coolant being introduced into the centre and exhausted at the two ends of the reactor. Another remarkable difference is the employment of a pre-stressed concrete pressure vessel, lined with sheet steel to ensure leak-tightness. This pressure vessel is kept cool by circulating cold carbon dioxide gas between the thermal shield and the steel lining. The fuel consists of an alloy of natural uranium and a small quantity of aluminium, each fuel element being sheathed in, and mechanically secured to, a finned magnesium tube. The reactor also has provision for re-charging and discharging fuel whilst the reactor is operating.

B. Water-Cooled Reactors: (i) Non-Boiling

Water-cooled reactors may be divided into (i) non-boiling and (ii) boiling reactors; examples of non-boiling installations will be considered first.

5. *The Russian Atomic Power Station.*—This was the only "dark horse" of the conference. The major details of all the other working or building power reactors described had been known for a considerable time, but nothing whatsoever was known of the RAPS. The most striking fact about



Model of a proposed pressurised-water reactor designed for the U.S. Atomic Energy Commission programme. Light water serves as both coolant and moderator. (Item 10)

TABLE II.—A COMPARISON OF WORLD POWER REACTORS

No., Fig., Paper, Country	Owner, Designer, Location	Name, Programme, Operating date	Fuel, Investment, Heat rating	Fertile, Conversion ratio, Product	Moderator, Rating, Temp.	Coolant, Rating, Outlet Temp.	Fuel Can, Heat Flux, Maximum Temp.	Power (MW) Heat	Power (MW) Elec.	Capital (Million dols.) per kW (dols.) kW hr. (mills.)
A.—GAS COOLED REACTORS										
1. (Fig. 1)	U.K. A.E.A.	Calder Hall	U nat. (c)	U238	Graphite	CO_2; 105 p	—	—	30	21 to 28
P406 (*a*)	U.K. A.E.A.	Plutonium (*b*)	—	—	—	—	—	—	per	350 to 555
U.K.	Calder Hall	1956	—	Pu	—	350 deg. C.	400 deg. C.	—	reactor	7 (*d*)
2. (Fig. 1)	C.E.A. Industry	CEANP Power	U nat. 125 tonnes	U238	Graphite	CO_2 or H_2	—	—	75	27
P390 (*a*)	—	(*b*)	~ 2·5 kW per kg.	— Pu	—	—	—	—	per	350
U.K.					—	—	—	—	reactor	7
3. (Fig. 2)	—	G1 (*a*)	U nat.	U238	Graphite	Air (At.)	Mg	40	5·75	—
P333	—	Plutonium	100 tonnes	—	—	—	—	—	gross	—
France	Marcoule	1956	0·4 kW per kg.	Pu	—	220 deg. C.	—	—	(*b*)	—
4. (Fig. 3)	—	G2	U nat.	U238	Graphite	CO_2	Mg	—	30	—
P337	—	Plutonium	100 tonnes	—	—	—	(*a*)	—	—	—
France	Marcoule	1957	~ 1·2 kW per kg.	Pu	—	300 deg. C.	400 deg. C.	—	—	—

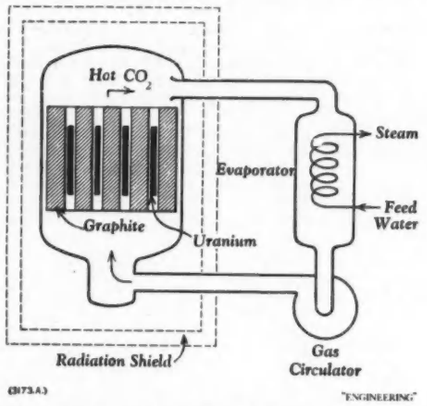


Fig. 1 Scheme for Calder Hall station. It is a thermal reactor using natural uranium fuel.

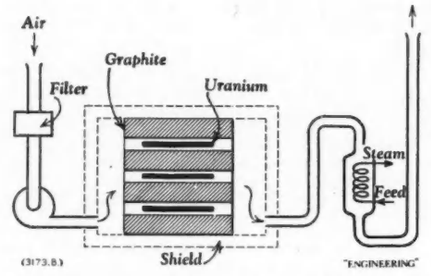


Fig. 2 The French G1 reactor at Marcoule is air cooled and graphite moderated.

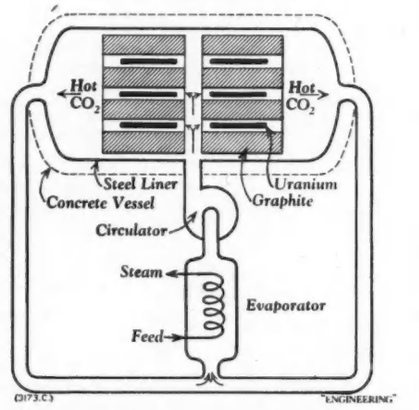


Fig. 3 The carbon-dioxide cooled G2 reactor has a split pile with horizontal fuel channels.

the reactor is that it reveals that the U.S.S.R. has an isotope separation plant able to supply considerably enriched uranium for their reactor projects. In the RAPS this enrichment (5 per cent. uranium 235, remainder uranium 238, possibly alloyed to improve fuel-element life) is used to off-set the neutron absorption resulting from the use of stainless-steel cans and coolant channel tubes. As in the Hanford design study (item 6, Table II), which, however, employs zirconium coolant tubes, the coolant tubes sustain the full internal pressure of 100 atmospheres and must therefore be relatively thick. No claim is made that this station is an economic proposition, but using the technological experience provided by it the Russian engineers intend to build 100 MW (electric) power stations using two 200 MW (heat) reactors of this type which are expected to be economical. Probably zirconium would eventually replace much of the stainless steel in the commercial designs.

An advantage of the single-ended feed and exit used in the RAPS reactor is that no special provision is needed to accommodate longitudinal expansion of the pressure tubes. A disadvantage is that it introduces yet more absorbing material within the reacting core. (RAPS is illustrated on page 493.)

6. *A Graphite Moderated Nuclear Plant Design.*—This is a design study by the Reactor Design and Development Unit of the Hanford Products Operation group of the General Electric Company. It is of interest to compare this large 800 MW (heat) reactor proposal with the smaller (200 MW heat) reactors of similar basic type, i.e., water cooled graphite moderated, which the U.S.S.R. intends to build as an extrapolation of the 30 MW (heat) RAPS experience. The Hanford proposal is a natural extrapolation of the 10 years of experience with similar reactors at Hanford itself. The principal differences from the RAPS are that the coolant channels are horizontal, the pressure tubes and fuel cans are of zirconium and, as a consequence, the required enrichment is only 0·92 per cent. uranium 235 (natural uranium contains 0·725 per cent. uranium 235) compared with 2·5 per cent. uranium 235 for the smaller 200 MW (heat) Russian reactor proposal using stainless-steel pressure tubes and fuel cans. The graphite moderator is kept in an atmosphere of helium, as in the RAPS, which is also used to cool the graphite and to dry it out in event of a pressure-tube failure.

BORON-STEEL BALLS FOR EMERGENCY SHUT-DOWN

One novelty of this reactor proposal is the gravity operated safety device. Should the normal control-rod system fail, 26 hoppers full of boron-steel balls would be emptied into 26 vertical slots in the graphite. The balls can be restored to their hoppers by means of an electromagnetic conveyer. A further interesting safety measure is the proposal to fit large flywheels to the electric coolant pumps to enable the pumps to be kept running long enough after a main power failure to ensure that the emergency low-power supply needed to keep the pumps running for shut-down cooling (to remove radioactive decay heat, as opposed to fission heat) can be brought into operation.

Because of the danger of flashing all the water into (radioactive) steam in the event of rupture of the primary coolant circuit coupled with the possibility of chemical reaction between molten (radioactive) metals and water, the whole reactor and auxiliaries would be housed within a 225 ft. diameter steel sphere.

Notes on Table II

Column headings, explanation:

Col. 1. Papers presented at the Geneva conference were given reference numbers, for example P 406; they are to be published in book form next year (see ENGINEERING, September 16, page 365).

Col. 3. The following letter names for reactors have been used in these tables for cases where no recognised letter name exists:

CEANP = Central Electricity Authority Nuclear Power stations.
RAPS = Russian Atomic Power Station.
RAPS(F) = Russian Atomic Power Stations (Future).
HGPWR = Hanford Graphite Pressurised-Water Reactor.
H_2 PWR = Light-Water Moderated (H_2O) Pressurised-Water Reactor.
D_2 PWR = Heavy-Water Moderated (D_2O) Pressurised-Water Reactor.
H_2 BWR = Light-Water Moderated (H_2O) Boiling-Water Reactor.
D_2 BWR = Heavy-Water Moderated (D_2O) Boiling-Water Reactor.

Col. 4. Fuel: U nat. = Natural uranium (0·725 per cent. uranium 235).

U, *x* per cent. 235 means *x* per cent. uranium 235, remainder uranium 238.

U nat + 235 means mixed fuel elements, some natural uranium, some of pure uranium 235.

Investment: Total investment in core of natural or low enrichment uranium given in tonnes or tons, as quoted in paper. 1 tonne = 1,000 kg. 1 ton = 1,018 kg.

Total investment in core of highly enriched uranium (e.g., 90 per cent.) or pure fissile material given in kg.

In case of highly enriched uranium this usually refers to uranium 235 content only.

Heat rating: For natural or low enrichment uranium heat-rating is given in kilowatts per kilogram (1 kilogram of natural uranium costs 40 dols.)

For pure fissile material heat rating is given in kilowatts per gram (1 gram fissile materials costs 30 dols.)

Col. 5. Fertile: Two possible fertile materials, uranium 238 which converts to plutonium, and thorium which converts to uranium 233.

Conversion ratio: Number of atoms of product fissile material formed by transformation of fertile material for each original fissile atom burned.

Col. 6. Moderators: H_2O = water, D_2O = deuterium oxide = heavy water.

Rating: This figure is of economic interest in heavy-water moderated reactors. Usually figures given refer to entire investment of D_2O in whole system (core plus external circuit). Given as kilowatts per kilogram. D_2O costs 60 dols to 90 dols. per kg.

Col. 7. Coolant: Figure following coolant type is working pressure in lb. per square inch.

Rating: This figure is of technical interest in pressurised-water and boiling-water reactors, referring to the heat extraction rate attainment. In this table it refers to power density in whole liquid contents of core of light-water moderated reactors, to coolant tube contents only of heavy-water moderated reactors (because bulk of moderator in this case must be kept cool if practicable).

Outlet temp: Outlet temperature of coolant.

Col. 8. Heat Flux: usually refers to average heat flux at fuel-can surface for whole core.

Max. Temp.: Maximum can temperature attained in reactor.

Col. 10. Capital: Usually this is the cost (in millions of U.S. dols.) of the entire plant (per reactor) including cost of electricity generation plant.

Per kW (dols.): Cost in dollars of each kilowatt of plant capacity.

kWhr. (mill): Cost (1 mill = 0·001 dol.) per kilowatt hour delivered.

Additional information concerning the reactors as numbered:

1. (*a*) Data also taken from "Nuclear Reactors and Power Production," by Sir Christopher Hinton (James Clayton lecture to Institution of Mechanical Engineers, February 26, 1954), and "A programme for Nuclear Power," H.M.S.O., Cmd. 9389 (see ENGINEERING, vol. 177, page 313, 1954; and vol. 179, page 240, 1955, respectively).

(*b*) These reactors are primarily intended as plutonium producers, generating electric power as a by-product. Eight such are to be built: 4 at Calder Hall (two now building), plus 4 at Annan, Dumfriesshire.

(*c*) Natural or slightly enriched uranium fuel.

(*d*) The first reactors will produce electricity at 0·76*d*. per unit (= 9 mills.). If plutonium by-product is credited, this becomes 0·6*d*. per unit (= 7 mill) Natural uranium cost assumed £20,000 per tonne (= 56 dols. per kilogram).

2. (*a*) Information also from P. 406 and refs. in note 1(*a*).

(*b*) The reactors for the C.E.A. nuclear power stations will be primarily electricity producers, with plutonium as a by-product. Each station will have two reactors. Construction of two stations expected to start mid 1957. Two more will be started 1958-59.

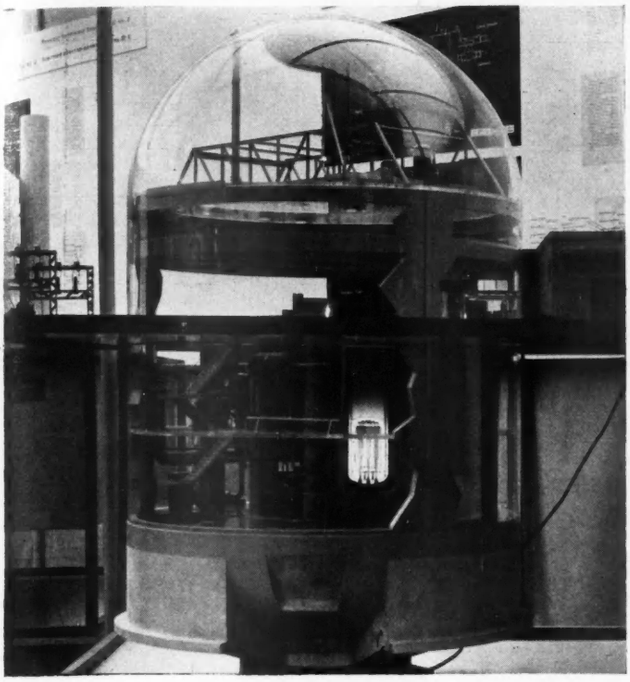
3. (*a*) G1 is a plutonium producer, to which a heat recovery plant has been added.

(*b*) Blower power is about 5·6 MW, so net electric power output is negligible.

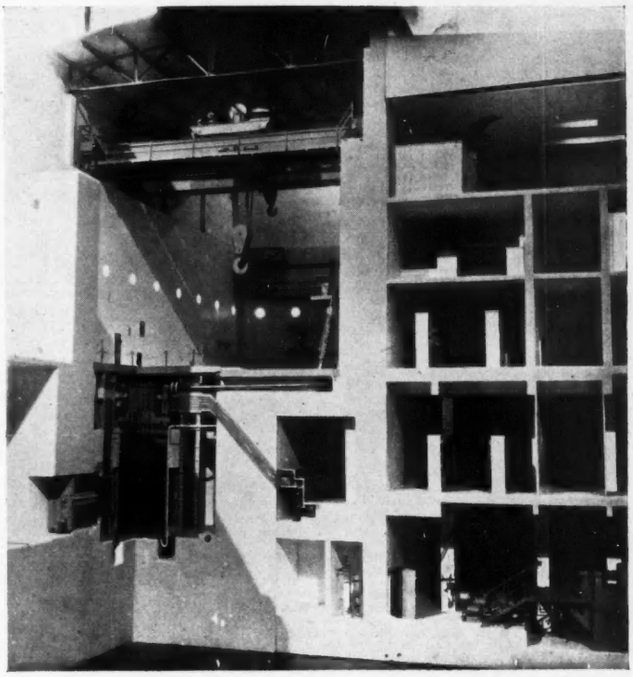
4. (*a*) Fuel maximum temperature = 550 deg. C.

Assuming 3,000 MWd per ton fuel burn up, and re-charging one-sixth of the charge on each occasion, the reactor would be shut down for re-charging every 27 days. The minimum shut-down time would then be 38 hours owing to decay-product reactivity poisoning effects. The estimated power cost is less than 0·7 mills per kW hr. which in fact makes this one of the most economic proposals presented.

7, 8, 9, 10 *and* 11. *Pressurised-Water Cooled, Light-Water Moderated Reactors.*—Only one of this class of reactor was described in detail at the conference, namely the Shippingport PWR. The other four reactors tabulated have been included for reference, since this is an important class of reactor as evidenced by the number in this class either working or under consideration. The first power-producing unit of this class was the land-based version, named STR-1, of the (identical) Nautilus power plant, and the same system is to form the basis of the Army Packaged Power Reactor (APPR) and two further Power Demonstration Programme reactors proposed by



A full-scale power plant demonstration planned by the U.S. will employ the EBWR (Engine Cold Boiling Water Reactor) now building. (Item 19)



Sectioned model of the 5-MW Russian atomic power station, which uses enriched uranium (5 per cent. U235, remainder U238). (Item 5)

the Consolidated Edison group and the Yankee Atomic Electric group. (A model Edison plant is shown at the foot of page 491.)

The use of light water as moderator necessitates some degree of enrichment of the uranium fuel in the U235 isotope. In the Shippingport reactor this is achieved by using a highly enriched "seed" (24 elements) and a natural uranium oxide "blanket" (93 elements). In order to secure adequate burn-up of the fissile content (initially U235 only, later both U235 and the plutonium formed from the U238) it is necessary to burn at least two seed elements for each blanket element consumed.

It is of interest to note the basic criteria for the thermal design of the PWR, especially in comparison with the boiling reactors discussed later. These are as follows:

(*a*) Nucleate boiling must not occur at the hot spots during steady operation.

(*b*) Bulk boiling must not occur in water leaving the hot channel either during steady operation or normal power change transients.

(*c*) Fuel element internal and surface temperatures must be compatible with the properties of the selected fuel element materials.

These requirements entail keeping the maximum temperatures of the coolant water and of the hottest fuel element surfaces below 335 deg. C., the saturation temperature at 2,000 lb. per square inch. Under these conditions the Zircalloy-2 cladding appears to be very satisfactory as regards corrosion. Even if the cladding fails neither the uranium oxide nor the U235-zirconium alloy reacts with the high temperature water. Also, neither material suffers serious radiation distortion so that high burn-ups are expected.

The central temperature in the hot-compacted and sintered uranium oxide blanket pellets may be as high as 1,200 deg. C.; this is still about 1,650 deg. C. below the melting point. It is not stated how a satisfactory thermal bond is made between the oxide pellets and the Zircalloy can (tube), but the pellets are said to be "ground to extreme accuracy" before loading into the tubing. In the plate-type seed elements an efficient metallurgical bond can readily be achieved, probably by hot rolling. The maximum surface heat fluxes are 75 watts per sq. cm. in the blanket, 120 watts per sq. cm. in the seed assemblies.

The temperature of the dry saturated steam supplied to the turbine from the evaporator is about 250 deg. C. at 600 lb. per square inch (depending on load). Using a special regenerative turbine arrangement a thermal efficiency of 29·5 per cent. is attained, compared with 26·5 per cent. for a simple condensing cycle—(both figures refer to 545 lb. per sq. in. gauge).

The whole nuclear portion of the Shippingport plant is to be built within a gas-tight steel containing vessel to meet the present safety requirement policy for this class of reactor.

12 *and* 13. *Canadian Pressurised Heavy-Water Power Reactor Proposals.*—The big difference between these proposals and the other pressurised-water schemes is that the use of heavy water as a moderator enables the fuel to be natural uranium only. The main disadvantage is that the capital investment in heavy water is very high. Nevertheless, the forecasts made in P4 and P11 at the Conference indicate that the cost of power may be fully competitive with the alternative PWR schemes using enriched uranium feed. There are some added engineering difficulties in ensuring very low losses of heavy water from the plant, but the leakage of primary water must in any case be kept very low even in a light-water PWR on account of the induced radioactivity.

An experimental power reactor of this type, named NPD (Nuclear Power Demonstration) is now being designed and is intended to be in service at Des Joachims, on the Ottawa River near Chalk River, in 1958.

14 *and* 15. *Non-Boiling Aqueous Homogeneous Reactor Schemes* (*HRT*1 *and HTR*).—Although requiring the solution of numerous difficult technical problems, the two-region non-boiling homogeneous thorium breeder scheme, which has yet to be tested in full-scale operation, appears to offer some remarkable possibilities for the development of really economical nuclear power. (A model of a homogeneous reactor is illustrated on page 497). The principles underlying the operation of this system are as follow.

HOMOGENEOUS BREEDER SCHEME

(*a*) The fuel feed to the plant will be natural thorium (which is not a fissionable element), as the oxide, thoria.

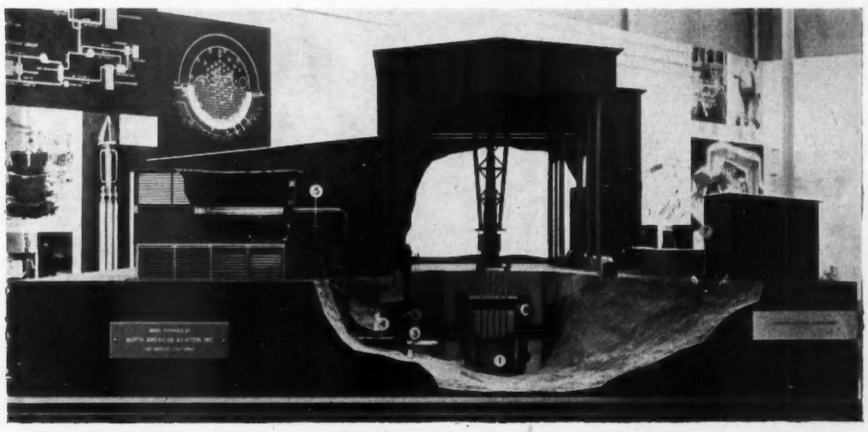
(*b*) This material is circulated outside the reacting core as a suspension of thoria in heavy water. Neutrons leaking out from the core are absorbed by thorium nuclei which are transmuted into protoactinium, which decays radioactively to form the fissile material U233.

(*c*) Some of the neutrons in the blanket cause fission of the newly-created U233, so that a considerable amount of heat energy is released in the blanket, and also more neutrons to contribute to the two nuclear processes.

(*d*) The circulating blanket suspension is continuously processed on a by-pass system by centrifuging out the thoria (containing U233) and passing the dried material thus separated from the heavy water to the U233 extraction plant.

(*e*) The U233 thus obtained is used as fuel for the core in the form of uranyl sulphate (UO_2SO_4) solution.

(*f*) The core solution is also circulated and processed on a by-pass system so as continuously to remove fission product solids (e.g., by centrifuging)



Model of SRE (Sodium Reactor Experiment) project, which will be a sodium-cooled graphite-moderated power reactor. It has been designed by the North American Aviation Company. (Item 23)

Notes on Table II—*continued.*

5. (*a*) 15 per cent. burn-up of uranium 235 is achieved, 20 per cent. by reloading in special fashion.
(*b*) Pressure tubes through graphite also made of stainless steel.
(*c*) 50—100 MW (electric) nuclear power stations are now being planned in U.S.S.R.
(*d*) Power cost said to be comparable with that from 1—5 MW thermal station.

6. (*a*) Fuel could consist of 0·92 per cent. uranium 235 in uranium metal pellets distributed uniformly in a magnesium-alloy matrix to give 65 per cent. uranium metal and 35 per cent. magnesium alloy by volume.
(*b*) Graphite contained in helium atmosphere.
(*c*) Fuel elements are 0·9 in. in outside diameter, 0·3 in. in inside diameter; cooled externally.

7. (*a*) A description of this installation, with very few design figures, is given in "Westinghouse Engineer," March and May, 1955.
(*b*) Fuel is "highly enriched uranium," alloyed with zirconium.

8. (*a*) Joint design by U.S.A.E.C. and Westinghouse. P. Dem. = Power Demonstration Programme reactor for U.S.A.E.C.
(*b*) There are 24 "seed" fuel elements composed of pure ("highly enriched") uranium 235 alloyed with zirconium, and 93 "blanket" fuel elements containing natural uranium-oxide pellets. During initial operation 40 per cent. of output power will come from seed, 60 per cent. from blanket, the latter increasing with time as plutonium is formed. Ratings: seed: 1·54 kW per gm., blanket 10 kW per kg.
(*c*) The average power densities for whole core contents are: 80 kW per litre in seed zone, 30 kW per litre in blanket zone. Average over whole core is 55 kW per litre. Figure in table is for rating of coolant liquid only in core on assumption fuel elements occupying about one quarter of core volume. Power density (rating) is then directly comparable with boiling reactor coolant ratings quoted.
(*d*) Saturation temperature for 2,000 lb. per sq. in. water is about 336 deg. C. Metal surface is operated "a few degrees" below this. Average heat flux is 75·5 W per sq. cm., maximum about 120 W per sq. cm.
(*e*) Sufficient heat will be available from the first core to generate 60 MW electric power. A thermal efficiency of 29·5 per cent. is expected.
(*f*) Provision is being made to introduce improved cores as development proceeds, thus to bring the total plant output up to 100 MW (electric), the installed capacity of the generator.

9. (*a*) Data from "Power Reactor Package," by Livingston and Block, Oak Ridge National Laboratory (O.R.N.L.) (Nucleonics, May, 1955).
(*b*) O.R.N.L. carried out preliminary study. Contract now placed with American Locomotive Company. (O.R.N.L. = Oak Ridge National Laboratory.)
(*c*) Fuel "highly enriched uranium."
(*d*) Power and cost figures refer to O.R.N.L. design study, 60 per cent. load factor. Contract reactor to produce 10 MW heat, 1·7 MW electricity, and contract price is 2·2 million dols.

10. (*a*) Pressurised water reactor for U.S.A.E.C. Power Demonstration Programme.
(*b*) A further 96 MW will be added from oil-fired superheater.

11. (*a*) Not described at Conference.
(*b*) Y.A.E. = Yankee Atomic Electric Co. PDP = Power Demonstration Proposal (submitted to U.S.A.E.C.).
(*c*) Monsanto and Fluor Corporations.
(*d*) If approved to proceed.
(*e*) Pressurised water, assumed light.

12. (*a*) Data taken from "Atomic Energy in Canada, 1955" issued at Geneva by Atomic Energy of Canada Limited. (A.E.C.L.)
(*b*) Des Joachims is a village on the Ottawa river bout 20 miles from Chalk River.
(*c*) NPD = Nuclear Power Demonstration.

13. (*a*) This is not a specific reactor design but the conclusions from a general economic study of heavy water natural uranium power systems based on considerable experience of high powered research reactors run on heavy water and natural uranium. They are of considerable interest in comparison with the more specific reactor proposals or actual projects listed in the rest of the table.
(*b*) 3,000 MW days per ton fuel irradiation has been achieved in Canadian piles. 5,000 MW days per ton thought to be a reasonable objective. Complete fuel rods expected to cost 44 dols. per kg.
(*c*) 0·8 is the conversion ratio assumed in P4 by the same author and assumed to apply to the estimates in P11 quoted.
(*d*) D_2O assumed to cost 66 dols to 88 dols. per kg.
(*e*) Based on 22 per cent. thermal efficiency.
(*f*) Figures quoted as 200 dols. to 300 dols. per kW installed capacity.

14. (*a*) The Homogeneous Reactor Test (HRT-1) described in P498 is the direct successor to the Homogeneous Reactor Experiment (HRE) which was dismantled early in 1954 after two years of successful experiment.
(*b*) The nuclear reaction takes place in two physically separated regions, core and blanket. Uranium 235 or uranium 233 solution in heavy water as uranyl sulphate is used in the core, uranium or thorium oxide as a suspension in heavy water is used in the blanket. 2·8 kg. is fissile content of core (= critical mass) only. External hold-up must be accounted.
(*c*) Thoria suspension in heavy water.
(*d*) 17 kW per litre of core volume. Mean rating of core plus external circuit hold-up might be a fifth of this (see 15 (*c*)). In the HRE tests power densities of up to 30 kW per litre of core were attained.

15. (*a*) As in 14 (*b*); solution of 2·8 gm. fissile uranium per litre heavy water in core.
(*b*) Suspension of 1,130 gm. thorium (as thorium oxide) per kg. of heavy water (equivalent to 1,000 gm. per litre).
(*c*) 190 kW per litre of core volume. Mean rating of core plus external circuit hold-up is only 36 kW per litre.
(*d*) Based on planned nominal electricity output of 100 MW and overall station thermal efficiency of 23 per cent.
(*e*) This excludes thoria, fissionable material and heavy water inventories. Compares with 15 million dols. for comparable coal-burning power station.

16. (*a*) Intermediate-enriched uranium as oxide suspension in light water.

17. (*a*) Design study started as PWR, later changed to BWR.
(*b*) Moderator rating of about 1·0 MW per litre D_2O as boiling water reactor. 14 tonnes of D_2O in core, external hold-up not known but assumed small for BWR use.
(*c*) Max. fuel temperature 380 deg. C.
(*d*) As PWR.
(*e*) As BWR. Moderator rating quoted would also apply to this case only.

TABLE II.—A COMPARISON OF WORLD POWER REACTORS—*continued.*

No., Fig., Paper, Country	Owner, Designer, Location	Name, Programme, Operating date	Fuel Investment, Heat rating	Fertile, Conversion ratio, Product	Moderator, Rating, Temp.	Coolant, Rating, Outlet Temp.	Fuel Can, Heat Flux, Maximum Temp.	Power (MW) Heat	Power (MW) Elec.	Capital (Million dols. per kW (dols.) kW hr. (mills.)
B. WATER-COOLED (i), NON-BOILING REACTORS										
5. (Fig. 4)	—	RAPS	U, 5 per cent. 235	U238	Graphite	H_2O; 1,500 p.	Stainless steel	30	5	—
P615	—	Power	(*a*)	0·32	—	—	(*b*)	—	(*c*)	—
U.S.S.R.	Moscow	June 27, 1954	—	Pu	600 deg. C.	270 deg. C.	175 W per sq. cm.	—	—	(*d*)
6. (Fig. 5)	—	HGPWR	U, 0·92 per cent. 235	U238	Graphite	H_2O; 1,860 p	Zr alloy	800	223	65
P492	Hanford	Study	45 tons (*a*)	—	(*b*)	—	(*c*)	—	—	289
U.S.A.	—	None	17·8 kW per kg.	—	—	310 deg. C.	—	—	—	< 7·0
7. (Fig. 6)	U.S. Gov.	STR-1 and 2	U235 (*b*)	None	H_2O	H_2O	Zr	—	—	—
(*a*)	Westing-house	Nautilus	—	—	—	—	—	—	—	—
U.S.A.	Idaho	May 31, 1953	—	—	—	—	—	—	—	—
8. (Fig. 6)	U.S. Gov.	PWR	U nat. + 235	U238	H_2O	H_2O; 2,000 p	Zircalloy 2	200	60	85
P815	A.E.C. & W (*a*)	P. Dem.	12 t. + 52 kg. (*b*)	0·8	—	70 kW per ltr.	75 w. per cm.	to (*e*)	to (*f*)	~ 1,000
U.S.A.	Shipping-port	1957	10 K/K. 1·5 K per gm.	Pu	285 deg. C.	285 deg. C. (*c*)	~330 deg. C. (*d*)	340	100	—
9. (Fig. 6)	U.S. Gov.	APPR	U235 (*c*)	None	H_2O	H_2O	Stainless steel	10	1	1·7
(*a*)	O.R.N.L. (*b*)	Army	25 kg.	—	—	—	—	(*d*)	—	936
U.S.A.	Fort Belvoir	1958	0·4 kW per gm.	—	—	230 deg. C.	—	—	—	53·3
10. (Fig. 6)	Consolid-ated Edison	H_2OPWR	—	—	H_2O	H_2O	—	500	140	55
—	Babcock	P. Dem.(*a*)	—	—	—	—	—	—	(*b*)	—
U.S.A.	Peckskill	1959	—	—	—	—	—	—	—	—
11. (Fig. 6)	YAE (*b*)	(Yankee)	—	—	H_2O (*e*)	H_2O (*e*)	—	—	100	20 to 25
(*a*)	Monsanto (*c*)	PDP	—	—	—	—	—	—	—	—
U.S.A.	Rowe, Mass.	1957 (*d*)	—	—	—	—	—	—	—	—
12. (Fig. 7)	A.E.C.L.	D_2OPWR	U nat.	U238	D_2O	D_2O	Zr	—	20	11
(*a*)	Can. G.E.	NPD (*c*)	—	—	—	—	—	—	—	550
Canada	Joachims (*b*)	1958	—	Pu	127 deg. C.	260 deg. C.	—	—	—	—
13. (Fig. 7)	—	D_2OPWR	U nat.	U238	D_2O (*d*)	D_2O	Zr	900	200	—
P11	—	Design (*a*)	(*b*)	0·8 (*c*)	—	or	—	(*e*)	—	259 (*f*)
Canada	—	studies	—	Pu	—	H_2O	—	—	—	4 to 10
14. (Fig. 8)	U.S. A.E.C.	HRT-1 (*a*)	U233 or 5	Th (*c*)	D_2O (*d*)	D_2O; 2,000 p	None: Homo-geneous reactor	5 to 10	2	3
P498	O.R.N.L.	P. Dem.	2·8 kg. (*b*)	1·1 to 1·15	~ 3 kW per litre	17 kW per litre		—	—	—
U.S.A.	Oak Ridge	1956	1·8 kW per gm.	U233	300 deg. C.	300 deg. C.		—	—	—
15. (Fig. 8)	U.S. A.E.C.	HTR	U233 or 5	Th (*b*)	D_2O (*c*)	D_2O; 2,000 p	None: Homo-geneous reactor	440	100	20 to 25
P496	O.R.N.L.	P. Dem.	30 kg. (*a*)	1·1 to 1·15	36 kW per litre	190 kW per litre		(*d*)	—	(*e*)
U.S.A.	—	1959	14·6 kW per gm.	U233	300 deg. C.	300 deg. C.	—	—	—	—
16. (Fig. 9)	—	Homo-geneous (Design study)	U (*a*)	U238	H_2O	H_2O; 750 p	None: Homo-geneous reactor	0·25	Nil	—
P936	—		—	—	—	—		—	—	—
Nether-lands	—		—	Pu	—	—		—	—	—
17. (Fig. 10)	—	PWR/ BWR (Design studies) (*a*)	U nat.	U238	D_2O (*b*)	D_2O; 400 p	Al alloy	10 (*d*)	2·5	—
P879	—		9 tons	—	~ 1·0 kW per litre	—	(*c*)	15 (*e*)	—	—
Norway	—		1·7 kW per kg.	Pu	60 deg. C. (av.)	230 deg. C.	—	—	—	—

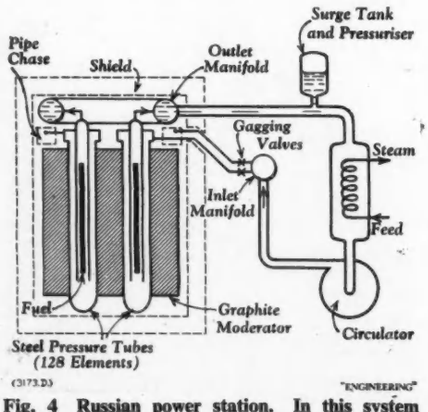


Fig. 4 Russian power station. In this system pressurised water serves as coolant and graphite as moderator.

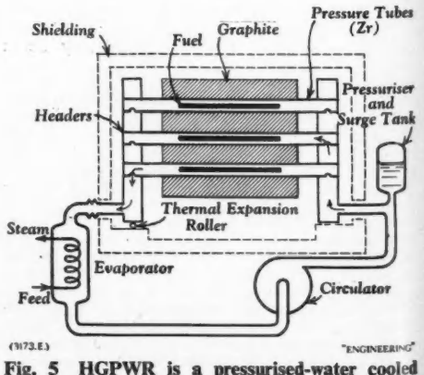


Fig. 5 HGPWR is a pressurised-water cooled graphite-moderated reactor, and is a study by the Hanford Products Operation group of the G.E.C.

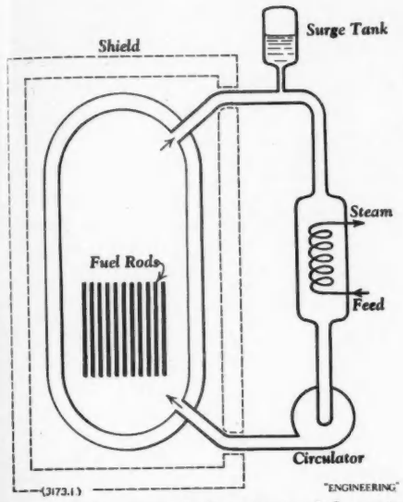


Fig. 6 U.S. pressurised-water cooled, water-moderated system (light water in both cases).

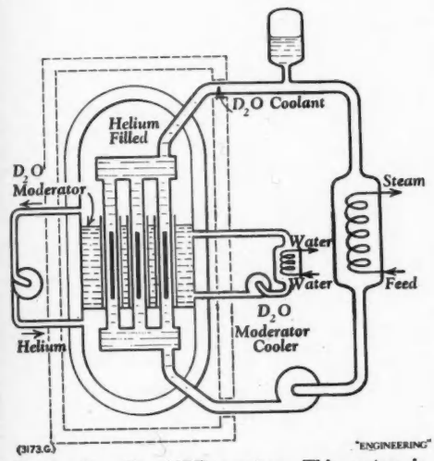


Fig. 7 Canadian NPD reactor. This system is moderated and cooled by heavy water.

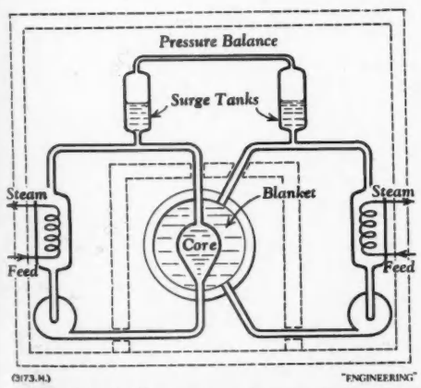


Fig. 8 Non-boiling aqueous homogeneous reactor scheme. Fresh fuel is bred from thorium.

and gases, thus removing the "ashes" of the "burned" U233.

(*g*) Useful heat is extracted from both circuits as in other PWR reactors.

The operation of this type of reactor appears to be remarkably simple. Because of its large degree of inherent nuclear stability (owing to the very large negative temperature coefficient of reactivity) no mechanical control rods are required. The average temperature of the core is controlled by varying the concentration of fuel, and the power level is governed solely by the rate of heat removal from the core. If the power demand falls, the core temperature rises, the liquid expands and so some fuel solution is

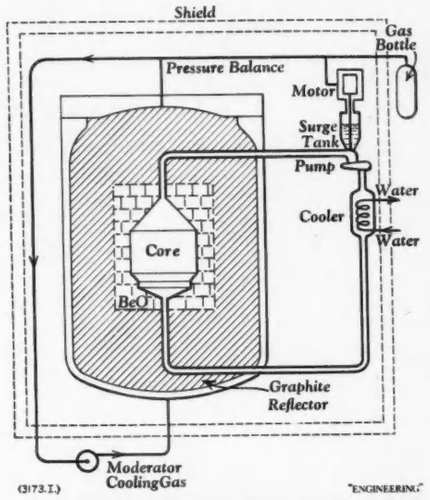


Fig. 9 Netherlands homogeneous reactor scheme using light water as both coolant and moderator.

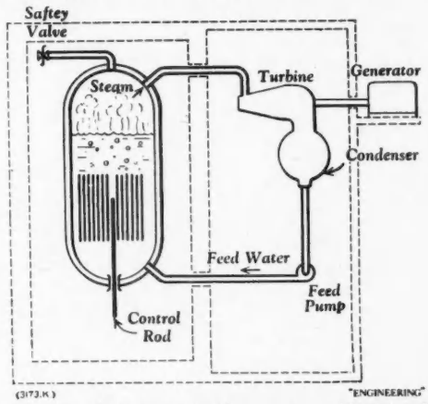


Fig. 10 Light-water boiling reactor with natural circulation. BER-III is already working on this system.

removed from the core and stored in the surge tank, thus reducing the core activity; and vice-versa if the power demand rises.

CONVERSION FACTOR MAY EXCEED UNITY

The outstanding advantages of the system as regards economics are as follow.

(*a*) Because of the absence of absorbing structural materials within the reacting regions (with the exception of the low-cross-section Zircalloy-2 "neutron window" core tank), because of the use of heavy water as moderator with its low neutron absorption cross-section, because of the high value of η (number of neutrons emitted per neutron absorbed in fissile material) for U233, and because neutron-absorbing poisons in the form of fission products can be considerably reduced by the continuous extraction process, there is a very good chance of an overall conversion factor considerably greater than unity for this system so that more U233 will be bred per neutron cycle than is burned by fission. In P496 the authors estimate that the doubling time of this process would be about 1,500 days for item 15.

(*b*) There is no solid fuel element to set a limit to attainable fuel irradiation time and consequent fractional burn-up of its fissile content (due to either metallurgical failure on account of radiation damage or to loss of reactivity due to depletion of fissile content). In effect, the whole reactor is a single fuel element whose condition is held roughly constant by continuous treatment.

(*c*) A high power density and low fuel inventory can be achieved. In the P496 proposal an overall fuel rating of 12 kW per gm. of fuel is expected. In the HRT-1 the fuel rating in the core alone is 1·77 kW per gm. of U235. The overall rating in the last case is less than 1·77 kW per gm. depending upon relative core and external hold-up volumes.

The primary difficulties associated with the system are concerned with the safe handling of the very high levels of radioactivity in the high-pressure, high-temperature circulating systems, and the corrosion problems encountered under the combined conditions of intense irradiation, high temperature and high pressure. There are numerous difficult chemical problems in the extraction systems, particularly on account of the intense radiation emitted by the materials being processed.

16. *The Netherlands Homogeneous Reactor Proposals.*—A fairly detailed scheme was presented for a small-scale experimental reactor using a suspension of enriched uranium in oxide form in light water. This would be used to investigate the properties of this class of system with a view to the ultimate development of a breeder reactor using thorium oxide enriched with U233 as a suspension in heavy water. This would be a one-region circulating fuel homogeneous thorium breeder reactor as defined in the United States paper P496, in which fuel and fertile materials are mixed. In this case it is proposed to surround the core vessel, presumably to be made of zirconium, with a beryllium oxide and graphite reflector, the whole assembly being contained within a gas-filled pressure vessel, the water within the thin-walled core tank being pressurised from the same gas source. No details of the expected economics are given.

The authors of P496 state that following a satisfactory zero-energy experiment, a small-scale enriched reactor will be built.

17. *The Norwegian PWR or Boiling-Water Proposal.*—This heterogeneous water-moderated reactor proposal has been taken last under class B(i) because it is a description of a design study which started off as a PWR and eventually developed into a boiling-water reactor, which is the next class to be described.

COOL MODERATOR

The design approach was conditioned by the desire to rely upon natural uranium fuel and heavy-water moderator only. This requirement enforces the use of cool moderator, and in this design entails some provision for heat insulation between coolant water and moderator in the form of low cross-section hot-water-proof ceramics. This has proved a difficult thing to obtain, and coupled with the new knowledge that enriched uranium would be available if the reactor, when constructed, failed to go critical at the operating temperature, led to the adoption of a boiling-reactor design. It was found by calculation that the loss of reactivity on account of the hotter moderator was just offset by the gain due to the omission of coolant tubes, so that the original aim of the design may still be preserved. It is of interest in this connection to compare this design with item 21, case 1, for a large D_2O (heavy water) boiling-reactor in which it is also considered necessary to keep the main bulk of moderator D_2O cooler than the coolant (boiling) D_2O.

The final proposition selected for further study is the D_2O boiling reactor with natural uranium metal fuel elements clad in aluminium-alloy tubes, operating at 427 lb. per sq. in. (as compared with 570 lb. per sq. in. for the PWR), 230 deg. C., giving some 10 MW of heat or 2·5 MW electricity for an investment of 14 tonnes (plus external hold up) of D_2O and 8·2 tonnes of uranium. It is to be housed in a rock cavern to contain any explosion.

Proposed applications for plant of this category include small-scale industrial power production, ship propulsion, and process heat for industry. The economics are not analysed, but it is again of interest to compare with item 21, case 1, in which the heat output is 10 MW per ton of D_2O compared with 0·7 or, at best, 1·4 MW per ton of D_2O in the present proposal.

B. Water-Cooled Reactors: (ii) Boiling

18. *The First Power-Producing Boiling-Water Reactor, BER-III.*—The description of this reactor given in P851 and of its two non-power producing predecessors, I (named "Borax") and II (which was an experimental core in BER-III pressure vessel), described in P481, has aroused great interest. The termination of the successful series of tests with Borax culminated in a run-away test to destruction effected by means of a spring-ejected control plate, which test went to prove that a reactor of this class is difficult to destroy because of its inherent self-regulation qualities, and that even when self-destroyed explosively does not present anything of the nature of a catastrophe. Practically all the fuel originally in the reactor could be accounted for within a radius of 350 ft., and it was considered that no large fraction of the material left the site in the form of air-borne matter.

BOILING REACTOR: SAFE AND SIMPLE

The main advantages of the boiling type of reactor may be enumerated as follow.

(*a*) The reduction of pressure within the reactor vessel for a given pressure and temperature of steam supplied to the turbine, make for either cheapness

TABLE II.—A COMPARISON OF WORLD POWER REACTORS—*continued*

No., Fig., Paper, Country	Owner, Designer, Location	Name, Programme, Operating date	Fuel, Investment, Heat rating	Fertile, Conversion ratio, Product	Moderator, Rating, Temp.	Coolant, Rating, Outlet Temp.	Fuel Can, Heat Flux, Maximum Temp.	Power (MW) Heat	Power (MW) Elec.	Capital (Million dols.) per kW (dols.) kW hr. (mills.)
(ii) BOILING REACTORS										
18. (Fig. 10)	U.S. A.E.C.	BER-III (*b*)	U, 90 per cent. 235	Nil (*c*)	H_2O	H_2O; 300 p	Aluminium	15	3·5	0·55 (*f*)
P851	A.N.L. (*a*)	Argonne	11·8 kg. 235	—	—	35 kW per litre	12·5 W per sq. cm.	—	—	100
U.S.A.	Idaho	Operating	1·3 kW per gm.	—	240 deg. C.	240 deg. C. (*d*)	215 deg. C. (*e*)	—	—	34·6
19. (Fig. 10)	U.S. A.E.C.	EBWR	U nat. + U 235 (*a*)	U238	H_2O (*b*)	H_2O; 600 p	Zircalloy 2	20	5	4
P497	A.N.L.	P. Dem.	4·5 t. + 19 kg.	0·7	—	25 kW per litre	12·5 W per sq. cm. (*c*)	—	—	800
U.S.A.	Lemont	1956	2·8 kW per kg.; 0·39 kW per gm.	Pu	252 deg. C.	252 deg. C.	265 deg. C. (*d*)	—	—	21·8 (*e*)
20. (Fig. 10)	N.P.G.	H_2OBWR	—	—	H_2O	H_2O	—	670	180	—
—	G.E. Co.	PDP (*a*)	—	—	—	—	—	—	—	—
U.S.A.	Chicago	1960	—	—	—	—	—	—	—	—
21. (Fig. 11)	—	D_2OBWR	U nat.	U238	D_2O (*d*)	D_2O, 600p.	Zircalloy—2	1,000	248	—
P495	(*a*)		43·4 tons	0·901 (*c*)	8·3 kW per litre	110 kW per litre	50W per sq. cm.			—
U.S.A.			23 kW per kg.	Pu	90 deg. C.	250 deg. C. (*e*)	(average)			7·7
(Fig. 11)		D_2OBWR	U, 0·92 per cent. 235	U238	D_2O	D_2O, 600p.		250	62	—
			10·8 tons(*b*)	0·869	—	—				—
			18·5 KW per kg.	Pu	90 deg. C.	250 deg. C.				14·6
(Fig. 11)		D_2OBWR	U, 0·85 per cent. 235	U238	90 per cent. D_2O + 10 per cent. H_2O mixed 600 p.			250	62	—
	Design		10·8 tons	0·766	—	—				—
	studies		18·5 kW per kg.	Pu	90 deg. C.	250 deg. C.				15·3
(Fig. 10)		H_2OBWR	U, 1·1 per cent. 235	U238	H_2O	H_2O, 600p.		250	62·5	—
			72 tons	0·84	—	40 kW per litre				—
			3·5 kW per kg.	Pu	250 deg. C.	250 deg. C. (*f*)				17·7
(*g*)		H_2OBWR	U, 1·15 per cent. 235	U238	H_2O	H_2O, 600 p.		250	61	—
			36 tons	0·82	—	80 kW per litre				—
			7 kW. per kg.	Pu	250 deg. C.	250 deg. C.				16·8
22. (Fig. 12)	—	Homogeneous	U233 or 5	Th (*c*)	D_2O	or H_2O	—	—	—	—
P624	(*a*)	Boiling	(*b*)	—	3-5 kW per litre	—	—	—	—	—
U.S.S.R.	—	—	1·5-3 KW per gm.	U233	—	—	—	—	—	—

or larger practicable core sizes, and a lower temperature duty for the fuel elements.

(*b*) The simplicity of the system is such that the required steam is formed directly within the reactor so that no auxiliary steam-raising equipment is necessary, with consequent saving in pumping power and capital investment.

(*c*) A high degree of inherent safety and self-limitation of reactivity under fault conditions is demonstrated to result from the effect of steam-bubble formation upon reactivity.

The first two points are brought out in Fig. 18, on page 499, which is taken from P497, and illustrates the savings of pressure, pumping power and equipment for a steam delivery of 600 lb. per sq. in.

The disadvantages are that (i) the steam is some what radioactive, so that the power plant requires special provision for operation and maintenance and (ii) the power output of the reactor is limited by the rate at which steam can escape from the reactor rather than by the heat-flux at the fuel element surface, so that the power density of the reactor may be less than can be attained with a non-boiling pressurised-water cooled core. Power densities of 20 to 30 kilowatts per litre of total core volume were attained in the BER-III reactor. The average power densities expected from the first Shippingport PWR core are just over 40 kW per litre of core, and it is expected to work this up to the region of 70 kW per litre with improved cores. Nevertheless, it is also possible to improve the power density of boiling reactors. The two likely methods are either the addition of a natural convection chimney over the core, or the use of forced circulation by means of a pump.

With regard to the radioactivity of the steam it is found that because of effective de-trainment of moisture and particulate matter the steam activity is down by a factor 10^4 on the water activity within the reactor. In this connection it should be remembered that in a PWR the primary circuit pumps and heat exchanger (evaporator) must handle the full activity of the reactor core water, although in a more highly rated BWR forced circulation of water within the reactor by means of an external pump circuit may well be needed.

EXPERIMENTAL SHORT CUT

The striking thing about the Borax and BER-III experiments is the boldness of their conception. Those responsible for these ambitious nuclear engineering experiments believe that by building experimental reactors of this type directly, instead of going through the more conservative stages of running loop tests in test reactors and carrying out numerous other auxiliary tests and additional refined calculations, they have obtained more useful results in shorter time with the use of fewer reactor technologists than would otherwise have been possible. They further suggest that this experience strongly suggests this procedure to have application to the investigation of other new reactor types. Indeed, this procedure was followed by the Oak Ridge National Laboratory in their homogeneous reactor programme: the HRE (Homogeneous Reactor Experiment), which had no power conversion equipment, was built in 1951 and dismantled for inspection after two years successful running. This is now being followed by a demonstration-size thorium breeder power producing reactor (HRT-1) on very much the same scale as the BER-III.

It is worth calling attention to a significant difference between the control problems in the homogeneous non-boiling reactor and the heterogeneous boiling reactor. In the first type an increase of power demand momentarily cools the reactor and the fuel solution contracts (due to its thermal coefficient of expansion) so that automatically more active solution flows into the core (and circuit) from the surge-tank, thus increasing reactivity and hence automatically increasing heat output to compensate for the changed conditions; and vice-versa. In the boiling reactor an increase in power demand reduces the steam pressure, momentarily, above the core space, thus increasing the steam voidage (relative volume of water occupied by steam bubbles) within the core, thereby increasing the total neutron leakage from the core and so reducing activity; and conversely. Therefore, although essentially a safe system in terms of a run-away, it is inherently an unstable system as regards power regulation. Therefore, in the EBWR (item 19 below) it is planned to regulate power demand changes within a 5 per cent. limit by perma-

Notes on Table II—*continued*.

18. (*a*) A.N.L. = Argonne National Laboratory.
(*b*) This reactor has been operated with two experimental cores. The figures quoted refer to the second core of highest rating.
(*c*) Not strictly true because of 10 per cent. residual uranium 238.
(*d*) 20-30 kW per litre average core power density; 30 to 40 kW per litre of water in core.
(*e*) Average heat flux = 12·5 W per sq. cm., maximum about 30 W per sq. cm.
(*f*) More than half the total cost of the entire plant was in the power conversion equipment and cooling facilities.

19. (*a*) Charge made up of 77 natural uranium fuel elements and 35 uranium 235 assemblies. (85 per cent. to 90 per cent. uranium 235.) Enriched elements contribute 37 per cent. of total heat output.
(*b*) Provision is made for changing the core to enable operation of heavy water (D_2O) at a later date.
(*c*) Average heat flux 12·5 W per sq. cm. Maximum at hot spots 44 W per sq. cm. Burn-out about 190 W per sq. cm.
(*d*) Maximum fuel temperature = 294 deg. C.
(*e*) Economic assessment assumes 10,000 MW days per tonne radiation of fuel, 40 dols. per kg. natural uranium, 30 dols per gm. uranium 235. For 4·5 MW (electric), power cost 34·2 mills per kW hr. For 9·0 MW (electric), power cost 21·8 mills per kW hr. Second cost includes installation of second 5 MW electric set. Average 10 MW coal-burning plant in U.S.A. produces power at between 10 and 12 mills per kW hr.

20. (*a*) PDP = Power Demonstration Proposal submitted to U.S.A.E.C.

21. (*a*) These are design studies only.
(*b*) In all except first case the core is "spiked" with enriched uranium fuel elements as the fuel burn-up proceeds to preserve reactivity up to 10,000 MW days per ton.
(*c*) Conversion ratio expected to be sufficiently high to maintain reactor critical for 10,000 MW days per ton fuel irradiation using natural uranium fuel additions only.
(*d*) First reactor has 100 tons of D_2O in reactor plus 20 tons in external hold-up. At 62 dols. kg. this contributes 1 mill. kW hr. to the power cost.
(*e*) Approximately 110 kW per litre of liquid in core flow channels. Main volume of moderator kept at much lower temperature. Average power rating of D_2O core only (excluding reflector) is 26 kW per litre. Average power rating for D_2O in whole system, including external hold-up, is 8·3 kW per litre D_2O.
(*f*) This uses natural convection of coolant. All other cases assume forced convection.
(*g*) As Fig. 11, but with close-spaced fuel elements and no special provision for cooling moderator separately.

22. (*a*) These are design studies only.
(*b*) Uranium in oxide form as aqueous suspension.
(*c*) Thorium in oxide form as aqueous suspension.

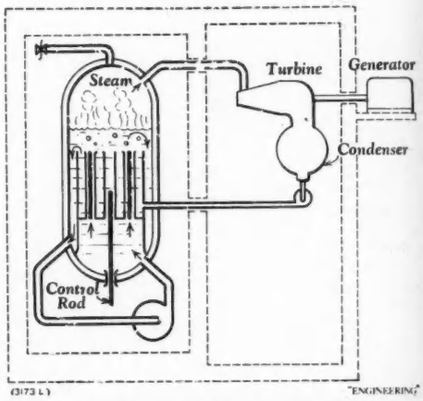


Fig. 11 Heavy-water boiling reactor with forced circulation. (U.S. design studios).

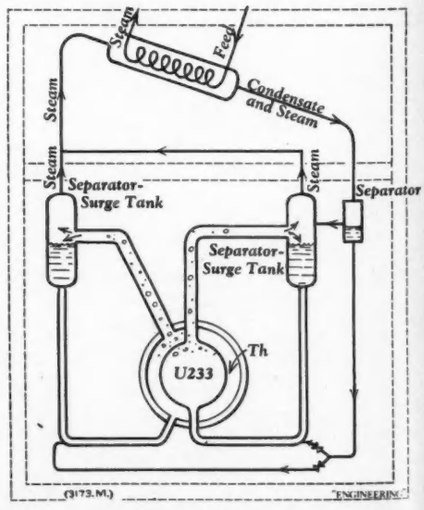


Fig. 12 Homogeneous boiling breeder scheme with natural circulation. Fissile uranium 233 is bred from thorium.

nently by-passing a nominal 5 per cent. of the reactor output steam past the turbine to the condenser, holding the reactor pressure constant by adjusting this by-pass to suit minor load changes. Large but slow changes of power are dealt with by automatically re-adjusting the reactor power level to maintain this 5 per cent. steam by-pass for all loads. Sudden large power changes are dealt with by automatically by-passing up to the full reactor steam output to the turbine condenser after which the reactor power level is reduced by inserting the control rods.

PROMPT TEMPERATURE COEFFICIENT

Unlike the homogeneous reactor, the boiling reactor also has a prompt temperature coefficient consequent on the instantaneous expansion of fuel elements with increase of power generation (and therefore of element temperature), and a delayed coefficient due to steam bubble formation. They differ yet again from the PWR types in this respect, which have neither the bubble-formation control or the concentration change effect. A PWR requires a much more carefully regulated control system.

19 *and* 20. *Full-Scale Boiling Reactor Power Plant Demonstrations.*—Two full-scale power plant demonstrations are planned. The first, EBWR, now building, is described in P497. It will yield 5 to 10 MW of power. The second is at present only in the proposal stage and no details are yet available, but it is listed in the table for comparison. It is of much larger power output: 180 MW compared with 5 MW. (A model of EBWR is illustrated on page 493, top left.)

The selected average core power rating upon which the EBWR design is based is 25 kW per litre core volume, following the BER experience. The bulk of the fuel is natural uranium (4,536 kg.), "spiked" with 19 kg of U235 to enable the reaction to proceed with a light-water moderator. Clearly in a national power scheme based on a uranium-to-plutonium breeding economy, or a thorium-to-U233 economy, such a reactor could be spiked with these fissile materials instead of U235. Provision is made in this reactor for operation with heavy water, which would enable operation on natural uranium alone. Therefore the primary circuit (including the turbine and condenser) is made to an extremely high standard of leak-tightness to avoid D_2O loss. This, coupled with the facts that the entire plant is built inside a gas-tight steel containing building and that provision is made for expansion of total capacity and other modifications, naturally results in higher capital cost than would be the case for a single-purpose reactor built in light buildings in a remote area.

21. *The Heavy-Water Boiling Reactor Proposals.*—In order to use a fuel feed of natural uranium only it is necessary to use heavy water as a moderator instead of light water. To achieve criticality and to operate with the moderator at high temperature it is necessary to use a core 10 ft. or more in diameter, plus 3 ft. or so for the reflector. Therefore such reactors must be used for large heat outputs if the investment charges against fuel and moderator are to be sufficiently small. The pressure-vessel thickness for 600 lb. per square inch working for a reactor of this size would be about 4 in. To provide 600 lb. per square inch steam from a PWR would require 2,000 lb. per square inch core working and provide an almost insuperable pressure-vessel problem. Further, the hold-up of heavy water outside the reactor itself is quite small (steam volume plus condensate only), whereas with a PWR an external hold-up volume almost equal to that within the reactor is unavoidable.

The use of heavy water, with its good moderating power and low nuclear capture cross section, enables the attainment of a conversion factor near to unity, so that reactivity of the fuel may be maintained to a high degree of burn-up provided the metallurgical difficulties can be overcome to permit the long exposure.

FUEL ELEMENT SPACING

To obtain a sufficiently high heat rating from the fuel investment it is necessary to form the elements into thin plates to avoid excessive fuel-element surface heat fluxes. Because of the longer neutron slowing down distance in D_2O as compared with H_2O (because deuterium has twice the mass of hydrogen), it is desirable to space the fuel elements further apart in D_2O than in H_2O, giving water-to-uranium volume ratios of 20 : 1 compared with 2 : 1. Further, it is desirable to reduce the surface area of uranium exposed directly to neutrons diffusing in from the moderator volume. This is in order to avoid excessive non-fissioning capture by U238 due to the very high "resonance" capture cross-sections of U238 for neutrons not yet fully slowed down to the equilibrium thermal velocity distribution. Therefore the fuel plates are arranged in clusters so that the outer plates act as screens which absorb such resonance-speed neutrons as diffuse into the fuel element volume. The inner plates are therefore prevented from capturing an excessive quantity of the yet unthermalised neutrons which they would have done if all the fuel-plate surfaces were equally exposed to the diffusing neutrons. This clustering of the plates results in a further advantage. It is only necessary to have high-temperature water circulation within the fuel arrays themselves, so that the bulk of the moderator can be kept cooler (average 90 deg. C.). This enables the thermal neutron velocity distribution to be centred on a lower speed than would be the case with hot moderator, and this, in turn, still further reduces the resonance capture effect (also neutron leakage), and hence the critical size is kept to a minimum (also the conversion factor is raised because of the lower leakage).

The lattice spacing (8 in. centres) actually chosen is a compromise between the need to keep the critical size small (needing large spacing) and to keep the heat output per unit volume of heavy water high (needing small spacing).

The paper also gives studies of some smaller plants (250 MW heat) and compares D_2O and H_2O cases. The authors' conclusions are: (*a*) the 1,000-MW D_2O reactor can produce power at half the cost of that from the H_2O reactor; (*b*) for small reactors H_2O is superior because the amount of D_2O per unit power output becomes uneconomic; (*c*) around 200 MW (heat), H_2O and D_2O are roughly equal economically.

22. *The U.S.S.R. Boiling Homogeneous Thorium Breeder Reactor Proposal.*—In this reactor proposal the use of either natural uranium in heavy water, or enriched or pure uranium (U235 or U233) in light or heavy water is planned, the uranium to be in the form of a solution of salt or a suspension of oxide. It is claimed that experiments have shown suspensions to be a workable proposition and that sedimentation is not a serious problem, being maintained uniform with ease by ebullition.

URANIA SUSPENSION CORE

The main proposal is for a breeder reactor with a thoria suspension blanket, also boiling. Thermosyphon circulation of the fuel and blanket solutions or suspensions is proposed in order to maintain homogeneity and to provide steam separation in a separate drum. It is claimed that an apparatus has been designed to "purify" (presumably to decontaminate of radioactivity) the steam by a factor 10^{10}. It is not proposed to pass this steam through a turbine, but to condense it in a condenser-evaporator heat exchanger.

Besides the usual advantages claimed for the homogeneous thorium breeder of the PWR type, the Russian authors claim: (*a*) the hold up of fissile content is less; (*b*) no forced circulation pumps are required; and (*c*) because of the high decontamination factor, no significant (delayed) neutron emission occurs in the heat exchanger, so that the steam produced is not radioactivated.

The claim is also made that this class of reactor is both stable and self-regulating, whereas the homogeneous PWR is said to be stable only. This does not appear to be the case, however, to judge from the HTR reports. There is, of course, a difference in the stability of the two classes of system on account of the steam void formation effect being added to the liquid thermal expansion and radiolytic gas production effects in the homogeneous PWR case.

C. Liquid-Metal Cooled Reactors

23. *The Sodium Reactor Experiment* (*SRE*).—This is an ambitious engineering-scale experiment aimed to demonstrate the engineering aspects of a high temperature (515 to 650 deg. C. outlet temperature) sodium-cooled graphite-moderated power reactor and to carry out the necessary experimental and development work required to lead up to the 75 MW (electric) power reactor (SGR, item 24) also being designed by the North American Aviation Company. The SRE will produce a nominal 20 MW of heat, but no power conversion equipment is being provided initially. (See illustration at foot of page 493.)

The graphite moderator blocks, hexagonal in cross-section and just under 11 in. across the flats, must be canned in thin (0·035 in.) sheet zirconium in order to prevent absorption of the sodium coolant by the graphite, which would cause excessive neutron losses. The graphite is cooled by flowing sodium over the outside surfaces of the zirconium cans. The insides of the cans are vented to the helium blanket gas space above the sodium surface to ensure pressure equalisation, having regard to the possibility of gas production by the graphite when irradiated. It is necessary to subdivide and cluster the fuel elements in order to keep the surface heat flux and uranium central temperatures to acceptable values. Using enriched uranium bars 0·75 in. in diameter the maximum central temperature is kept down to 650 deg. C., and the maximum surface heat flux to about 107 watts per square cm.

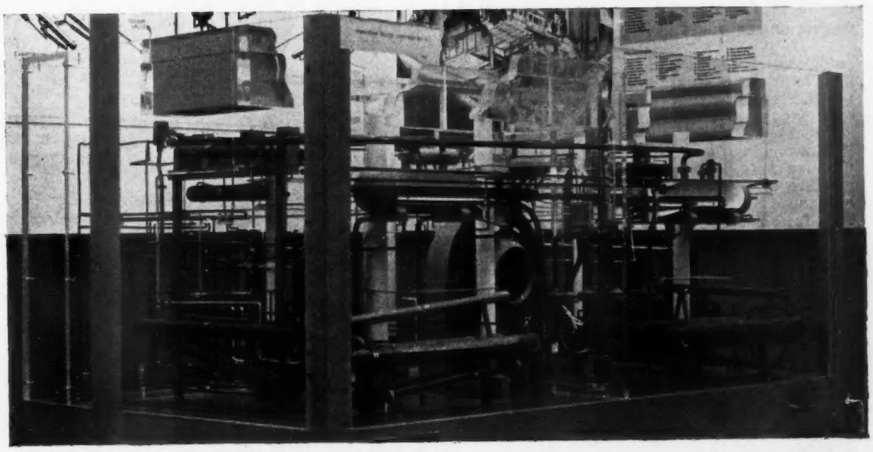
It is interesting to note that despite the fact that sodium is well suited to pumping by electromagnetic pumps, in fact mechanical pumps are to be used for this reactor. It seems probable that this has been inspired by the combined desires for ruggedness (avoidance of thin-walled pump tubes) and avoidance of irradiation of insulated windings in close proximity to the gamma-active sodium. Frozen sodium shaft seals are employed, helium blanketed to avoid reaction of the exposed cold sodium with the outside atmosphere.

24. *The Sodium Graphite Reactor* (*SGR*).—This proposal has now been taken up by the Consumers' Public Power District of Columbus, Nebraska, as one of the four industrial power demonstration proposals submitted by industry in which industry would bear 80 to 90 per cent. of the costs of the programme.

The studies described in P493 are based on what are considered to be conservative engineering limitations actually to be attained by the SRE (item 23). It will be seen from the table that the designers believe that this system can be developed to have a conversion ratio of about unity in a power reactor of large heat output (400 MW). Such a reactor would require no feed of fissile material, requiring only thorium from which to create its own fissile U233. The expected performance of this power system may be compared with the potentialities of the aqueous homogeneous thorium-to-U233 breeder and the fast fission U238-to-plutonium breeder. The SGR would not generate surplus fissile material as would the breeders, but would be self-sustaining on the thorium feed, and is capable of high temperature operation, leading to high power plant efficiencies of well over 30 per cent.

HIGH STEAM TEMPERATURES

The use of thorium metal with its superior metallurgical properties as compared with uranium is expected ultimately to enable the SGR type of



Model of homogeneous reactor. This system, which provided the basis of experiments carried out at the Oak Ridge National Laboratory, U.S.A., employs a core and blanket which are physically separate.

TABLE II.—A COMPARISON OF WORLD POWER REACTORS—*continued.*

No., Fig., Paper, Country	Owner, Designer, Location	Name, Programme, Operating date	Fuel, Investment, Heat rating	Fertile, Conversion ratio, Product	Moderator, Rating, Temp.	Coolant, Rating, Outlet Temp.	Fuel Can, Heat Flux, Maximum Temp.	Power (MW) Heat	Power (MW) Elec.	Capital (Million dols.) per kW (dols.) kW hr. (mills.)
C. LIQUID METAL COOLED REACTORS										
23. (Fig. 13) P499 U.S.A.	U.S. A.E.C. N.A.A. (*a*) S. Susana	SRE (*b*) P. Dem 1956	U, 2·8 per cent. 235 2 to 2·5 t. ~10 kW per kg.	U238 ~ 0·7 Pu	Graphite (*c*) ~550 deg. C.	Sodium (*d*) (*e*) 515 deg. C.	Stainless steel (*f*)	20	Nil (*g*)	4 (*h*) — —
24. (Fig. 13) P493 U.S.A.	C.P.P.D.C. (*a*) N.A.A. Nebraska	SGR PDP (*b*) 1959	U (*c*) 10·6 kW per kg. / U-Th (*d*) 0·7 kW per gm.	238 0·7 Pu / Th 0·9 233	Graphite — —	Sodium — 510 deg. C.	Stainless steel — —	250 (*e*) 400	75 100 125	— 300 to 200 11·5 to 7·0
25. (Fig. 14) P493 U.S.A.	— Brook-haven —	LMFR (*a*) Studies (*b*) —	U233 (*c*) ~170 kg. 3·2 kW per gm.	Th 1·05 U233	Graphite (*d*) —	Bismuth 22 KW per litre (*e*) 550 deg. C.	None — —	550	210	50 238 7·8
26. (Fig. 15) P813 U.S.A.	U.S. A.E.C. A.N.L. (*a*) A.N.L.	EBR (*b*) Argonne December, 1951	U, 90 per cent. 235 52 kg. ~0·03 kW per gm.	U238 1·01 Pu	None (*c*) —	NaK (*d*) — 316 deg. C.	Stainless steel — (*e*)	1·4	~0·2 (*f*)	— — —
27. (Fig. 16) P501 U.S.A.	U.S. A.E.C. A.N.L. Idaho	EBR II (*a*) P. Dem 1958	Pu-U alloy (500 kg.(*b*)) (1·0 kW per gm.)	U238 (1·5) Pu	None —	Sodium 480 deg. C.		60 (500)	20 (150)	(45) (300) (8·09)
28. (Fig. 15) (*a*) P405 U.S.A.	A.P.D.A. A.P.D.A. (*b*) Michigan	F. Breeder PDP (*c*) 58	Pu-U alloy — —	U238 — Pu	None — —	Sodium — —		300	90	29 323 —
29. (Fig. 15) P405 U.K.	U.K. A.E.A. U.K. A.E.A. Dounreay	Fast Breeder Experi-ment —	235 or Pu — —	U238 — Pu	None — —	Sodium — —	— — —	60	—	— — —
D. FLUIDISED SOLID COOLED REACTOR										
30. (Fig. 17) P938 Nether-lands	— — —	— Design study	UO_2 nat. 175 t. 1·7 kW per kg.	U238 — Pu	D_2O 3 kW per litre Cool	Fluidised UO_2 1,200 deg. C.	Graphite	300	—	— — —

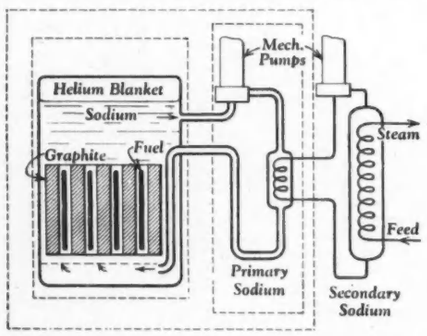


Fig. 13 Sodium graphite system; the graphite is carried in zirconium. It would be self-sustaining on thorium and could operate at high temperatures.

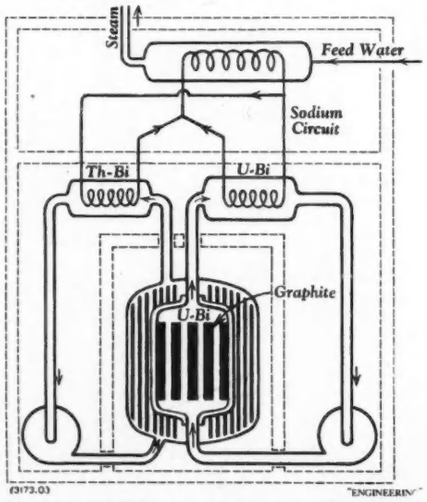


Fig. 14 LMFR bismuth-uranium liquid-metal fuelled reactor; it has a positive breeding gain.

reactor to produce steam temperatures to the limit of present power plant capabilities. The limitation of such attainment at present is the uncertainty regarding the performance of suitable zirconium alloys in liquid sodium at high temperatures, e.g. 650 deg. C. If neutron economy was neglected and stainless steel used for cladding the graphite, a sodum outlet temperature of 650 deg. C. could be obtained using techniques available at present in a thorium-uranium alloy fuelled reactor. The thorium central temperature would be about 1,100 deg. C., which is considered to be entirely acceptable.

25. *The Bismuth-Uranium Liquid-Metal Fuelled Reactor.*—This very promising proposal is at present in the preliminary experiment and design study stage. It is based upon the unique property of bismuth that it combines low neutron capture cross section with the ability to take into solution up to about 0·1 per cent. of uranium at reactor operating temperatures, which is sufficient to enable a thermal neutron reactor (but not a fast reactor) to work.

The advantages of liquid fuel systems have been discussed under 14 and 15 above. This liquid metal system retains many of these (positive breeding gain, continuous processing, complete fuel burn-up, high power density, continuous de-poisoning, etc.) with the added advantages of much higher coolant outlet temperatures and the absence of high pressures. No radiolytic gases are produced.

The primary difficulties at the present time are associated with corrosion, as with the HTR proposals, although these seem well on the way to solution, and the fact that many of the novel techniques proposed have yet to be demonstrated on a large scale. This led the authors of the paper, P494, to conclude that it will not be until the early 1960s that a full-scale breeder power plant can in fact be demonstrated.

URANIUM-BISMUTH FUEL SOLUTION

Experiments have shown that the uranium-bismuth fuel solution can be used directly in contact with the graphite moderator, thus avoiding moderator canning (e.g., as required in the SGR) with its associated neutron wastage. Because of the much lower thermal neutron absorption cross-section of bismuth (0·032 barns) as compared with sodium (0·49 barns), absorption of bismuth within the graphite porosity is not serious as in the SGR. It has also been shown that low chromium steel (2·25 per cent. Cr, 1 per cent. Mo) can be used for long-term containment at 550 deg. C. provided small quantities of magnesium and zirconium corrosion inhibitors are employed in solution in the bismuth. The authors consider that these results justify an assumed life of 10 to 20 years for a reactor built on these principles.

26. *The First Fast Fission Reactor to Produce Electric Power (EBR).*—This reactor is of historic interest since it produced the first electric power from a nuclear reactor, although this was in a sense only a heat recovery plant working at the comparatively low thermal efficiency of 17 per cent. Nevertheless, the 200 kW or so of power produced provided power for the building and area. The prime purpose of the

Notes on Table II—*continued.*

23. (*a*) N.A.A. = North American Aviation Co.
(*b*) SRE = Sodium Reactor Experiment.
(*c*) Graphite is canned in zirconium and immersed in sodium for cooling.
(*d*) All liquid-metal cooled reactors work near to atmospheric pressure.
(*e*) All main components have been stressed for 650 deg. C. working, a target operation temperature being aimed at during the experimental programme.
(*f*) A film of NaK (sodium potassium low melting point alloy) 0·010 in. average thickness provides heat conduction between the uranium metal surface and the stainless-steel cladding. Maximum uranium temperature = 650 deg. C.
(*g*) Not at present intended to provide a power plant.
(*h*) This figure does not include development costs, which bring the programme to about 10 million dols.

24. (*a*) C.P.P.D.C. = Consumers Public Power District of Columbia.
(*b*) The SGR proposal has now apparently become one of the four industrial Power Demonstration Proposals (PDP) submitted to the U.S.A.E.C. under which industry would bear 80 to 90 per cent. of the costs.
(*c*) First proposed core has fuel elements of enriched uranium metal 1·8 per cent. of uranium 235, initial loading content 443 kg. of uranium 235 (in 24·6 tonnes total uranium). Maximum uranium temperature 650 deg. C. (compare alpha-beta change point 660 deg. C.)
(*d*) Second proposed core has fuel elements of uranium 235-thorium alloy, 3·70 per cent. uranium 235. Maximum metal temperature is 870 deg. C., but this is not a limiting factor. Fuel rating shown in terms of fissile content. Initial fissile investment 360·4 kg. of uranium 235.
(*e*) The third set of power figures refers to possible future attainments using a thorium blanket instead of a graphite reflector, a larger core and improved core design, but retaining temperature limits of first and second cores. The conversion ratio would then be near unity,

25. (*a*) LMFR = Liquid-Metal Fuel Reactor, project of Brookhaven National Laboratory.
(*b*) Studies only, backed by substantial experimental work.
(*c*) About 670 parts per million uranium 233 solution in molten bismuth.
(*d*) Graphite in direct contact with bismuth solution.
(*e*) 22 kW per litre of bismuth in whole circuit. Cost of bismuth per litre of same order as cost of heavy water per litre. Figure should be compared with moderator ratings of D_2O moderated systems.

26. (*a*) A.N.L. = Argonne National Laboratory.
(*b*) EBR = Experimental Breeder Reactor. This is essentially a high fast flux fast fission research reactor with a demonstration scale heat recovery plant of about 17 per cent. overall thermal efficiency.
(*c*) Fast fission reactor. No neutron moderation.
(*d*) NaK is a low melting point alloy of sodium and potassium.
(*e*) Maximum fuel temperature = 357 deg. C.
(*f*) Recovery plant only for demonstration.

27. (*a*) EBR II: Experimental Breeder Reactor. One of the five Power Demonstration Programme reactors to be built under U.S.A.E.C. sponsorship. Building to commence in 1956.
(*b*) All figures in parentheses refer to a study of a 500 MW (heat) reactor of the same class to demonstrate the ultimate potentialities of the fast breeder system.

28. (*a*) Data taken from special paper issued by U.S. library at Geneva. Pumps indicated as mechanical.
(*b*) A.P.D.A. = Atomic Power Development Associates Inc., a group of 25 electric power systems, 4 manufacturing enterprises and 4 engineering organisations.
(*c*) PDP = power demonstration proposal submitted to U.S.A.E.C.

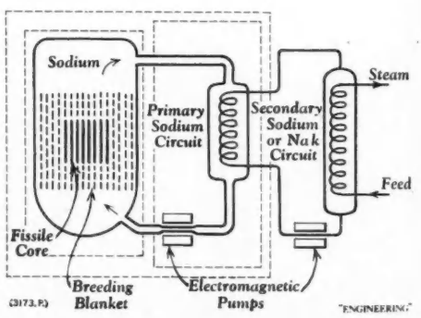


Fig. 15 Fast fission breeder reactor (EBR). This U.S. system produced the first electric power from a nuclear reactor (fuel 90 per cent. uranium 235).

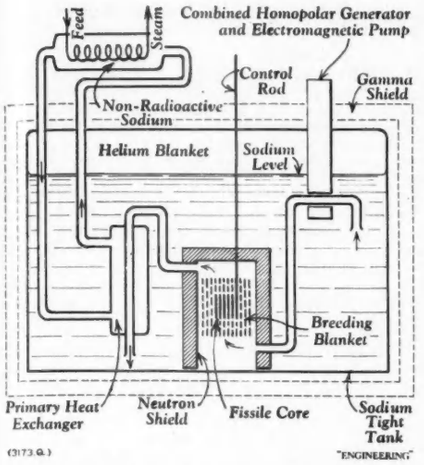


Fig. 16 Building of an experimental fast breeder reactor (EBR-II) will commence in the U.S. in 1956.

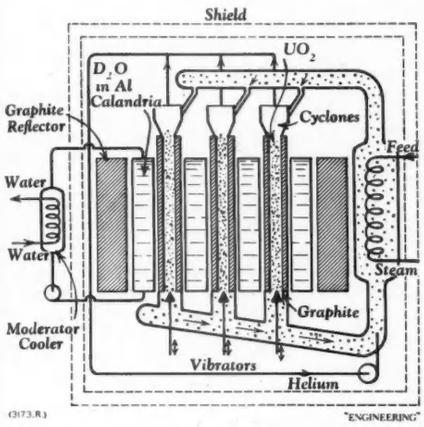


Fig. 17 Netherlands reactor system using dry fluidised solids as coolant. Vibrators promote flow.

reactor was experimental investigation into the principles of the fast neutron breeder reactor system. It was fuelled with 90 per cent. U235 clad in stainless steel, in contrast to the plutonium-fuelled Los Alamos fast fission research reactor. Since neither of these reactors are power projects they will not be further discussed. Note that the thermal rating of the fuel is 0·027 kW per gm. compared with 1·0 kW per gm. proposed for a 500 MW power fast fission breeder. "The Review of Fast Reactors," by W. H. Zinn (P814), should be noted by anyone studying these systems.

27. *The Experimental Breeder Reactor EBR-II.*—This installation is to be built, commencing in 1956, as part of the United States A.E.C. power demonstration programme. Once again this is a bold concept, incorporating many features of advanced reactor technology.

As regards power economics, in principle the fast reactors have all the advantages except, so far, the possibility of a liquid-fuel system. The design study ideas for a 500 MW reactor to be extrapolated from the EBR-II indicate fissile fuel heat ratings of the order 1·0 kW per gm., which may be compared with the ratings of other design study reactors in the following table:

TABLE III

Reactor	Power, megawatts (heat)	Fissile investment, kilograms	Fuel rating, kW per gram (= MW per kg.)
EBR study ..	500	500	1·0
SGR study ..	250	360	0·7
LMFR study ..	550	170	3·2
HTR study ..	400	30	14·6

It is seen that on fuel rating the large fast reactor shows up well by comparison with the nearest solid-fuel liquid-metal cooled thermal neutron reactor, but not so well by comparison with the liquid-fuel types. This showing is even worse when the external hold-up of solid fuel elements undergoing processing is taken into account. Nevertheless, the large breeding gain factor (1·5) attainable with the fast fission plutonium breeder appears almost completely to offset the apparently increased fissile inventory charge consequent upon the lower rating.

In the fast fission power reactor a large investment of fissile material, diluted to only a moderate extent with non-fissile material, is required to occupy a very small volume compared with most other reactor types. In order to obtain an economical heat rating from this material very high volumetric heat generation rates are entailed, leading to the need to subdivide the fuel into very small diameter rods, with consequent difficulties regarding mechanical support and flow distribution, in order to keep the surface heat flux and the maximum fuel temperature down to acceptable levels. Even so, the average heat flux at the fuel element surfaces is 315 watts per sq. cm. in the EBR-II, compared with 110 watts per sq. cm. maximum in the SRE design.

ELECTROMAGNETIC CIRCULATION PUMP

The engineering features of the EBR-II design are of considerable interest. As will be seen from the sketch, Fig. 16, the whole reactor, together with the primary electromagnetic circulation pump and the primary heat exchanger, and (not shown) the fuel-element storage block, is immersed in a large tank of sodium which is so designed and itself, in turn, contained, as to guarantee that the sodium content cannot be lost by leak or breakage, and in particular, that the sodium level could not fall below the level of the top of the reactor core.

This system offers the following very considerable engineering advantages.

(*a*) The core is always immersed in sodium, including pump failure conditions, and no circuit failures can violate this.

(*b*) The large thermal capacity of the sodium filling of the tank can deal with a great deal of heat under fault conditions, and natural convective cooling is available in emergency.

(*c*) Fuel elements can be changed immediately after shut-down because of the cooling available at all times on account of their continuous immersion in sodium during transfer from core to storage block, thus ensuring the removal at a sufficient rate of the considerable heat output arising from the radioactive decay of the fission products contained in the fuel.

(*d*) Leaks in the primary circuit are of little consequence; in fact, pipe expansion joints may be made a sliding fit and allow a small leakage.

(*e*) Although the intermediate sodium-to-sodium heat exchanger is very close to the reactor, because of the neutron shield around the reactor in fact the secondary sodium does not become radioactive, so that the only compartment of the plant requiring shielding is the sodium tank itself.

RECONDITIONING FUEL

The need to reduce fuel processing costs and the idle investment of fuel outside the reactor has led to the incorporation with the EBR-II of a pyro-metallurgical fuel element processing installation immediately adjacent to the reactor itself. Here the spent fuel elements will be de-canned and melted. It is found that 90 per cent. of the fission products and reactor poisons can be removed by slagging. Since the neutron-absorbing poisons (certain fission products) do not affect a fast reactor to the same extent as a thermal reactor, the residual 10 per cent. may be left in the melt and incorporated in the re-constituted fuel. After the replacement of the burned fissile material by means of suitable additions of plutonium to the melt, the re-conditioned metal is cast and re-fabricated into new fuel elements and re-inserted into the reactor. The whole process must, of course, be carried out behind shielding in gas-tight enclosures by remote control methods because of the gamma activity of the fission products and the combined toxic and radioactive hazards of plutonium and fission products.

A very ingenious design of combined homopolar generator and direct-current electromagnetic pump, the latter portion totally submerged in the sodium, has been designed for this reactor. It is interesting to contrast the coolant system of the EBR-II with the somewhat analogous system employed in the SRE, in which the gamma-active primary sodium is taken right outside the reactor tank and shield, through shielded pipe galleries to the (shielded) intermediate heat exchanger. In this case mechanical pumps with frozen shaft seals are employed instead of the electromagnetic type.

28. *The A.P.D.A. Power Demonstration Proposal.*—The group of companies constituting the Atomic Power Development Associates, Inc., have made proposals for a large-scale fast fission breeder power plant. Its power capacity and approximate costs, taken from a special (unnumbered) paper issued at the Conference, are indicated in the table. Few other details are as yet available, but the sketches given show the intermediate heat exchanger and primary circuit pump (which is indicated as mechanical) outside the main reactor tank. Neutron absorbing material is used for control rods instead of moving fuel element assemblies as in the EBR-II, but otherwise the core design appears similar. The whole plant would be enclosed in a gas-tight building.

29. *The Dounreay Fast Fission Breeder.*—Paper P405 on the Dounreay project deals in a qualitative fashion with the principles underlying the fast reactor project, and outlines in more detail the arrangements being made for the safe containment of the core and the primary sodium under all forseeable conditions. The 60 MW heat rating of this reactor is similar to that of the EBR-II reactor.

TWENTY-FOUR COOLING CIRCUITS

Instead of one large intermediate heat exchanger and one large pump all immersed in sodium, the Dounreay plant will have 24 intermediate heat exchangers and 24 electromagnetic pumps situated in an annular (air-filled) compartment around the core but shielded from its neutron emission to prevent radioactivation of the secondary sodium. Each pair of pumps will be powered by one of twelve Diesel-electric generator sets permanently connected to the pumps, thus avoiding dependence upon mains supplies and also all reasonable chance of total failure of the local power generation. To deal with the disposal of shut-down heat in this unlikely event of total power failure each of the 24 pump loops has in series with it a thermo-syphon sodium-to-sodium heat exchanger, with ultimate heat rejection to air via a natural-convection air cooler mounted in a chimney. The whole nuclear plant and primary-circuit equipment is to be contained inside a 135 ft. diameter steel sphere.

No details of the core construction are given beyond saying that the core size will be about 2 ft. in diameter and 2 ft. in height.

D. Mobile-Solid Cooled Reactor

30. *Reactors Using Dry Fluidised Solids as Coolant.*—A Netherlands paper, P938, outlines three reactor schemes based on the use of fluidised uranium

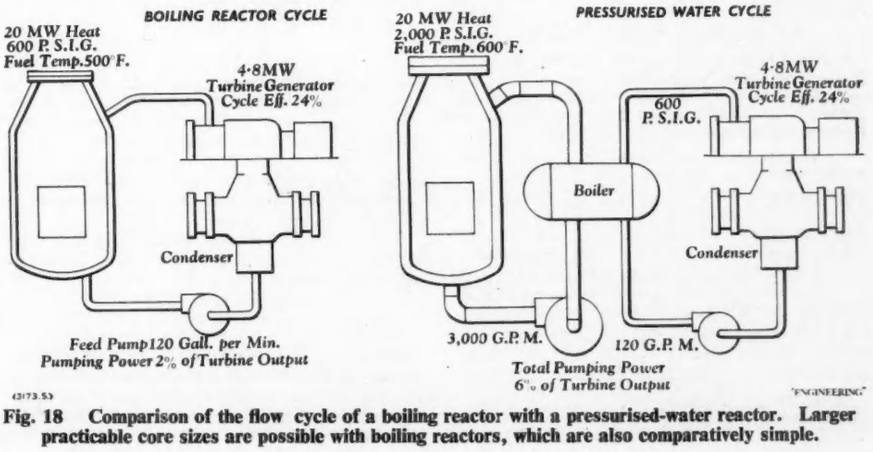


Fig. 18 Comparison of the flow cycle of a boiling reactor with a pressurised-water reactor. Larger practicable core sizes are possible with boiling reactors, which are also comparatively simple.

and thorium oxides. The most interesting proposal is for a 300 MW power reactor using cool heavy water as moderator and natural uranium oxide powder flowing inside about 250 graphite tubes which pass through the 10 ft. diameter moderator tank, which is presumably of aluminium calandria construction as for the heavy-water research reactors such as NRX.

The flow downwards through the reactor is promoted by vibrators at the bottom of each fuel channel, where the fuel leaves at a temperature of about 1,200 deg. C. The hot powder is then fluidised with helium, and used to raise steam, after which it is returned to the top of the reactor for recirculation. Some degree of continuous de-poisoning is thought practicable.

This novel reactor proposition is backed by some experimental work on the fuel-flow system, but is as yet nowhere near the state of development of the other reactor types described. Advantages claimed are: (*a*) it is possible to produce high quality steam without the need to pressurise the reactor; (*b*) the cheapest fuel can be burnt in this reactor, namely natural uranium in oxide form; and (*c*) a high conversion ratio is assured with the probability of being able to breed U233 from thorium (oxide).

PROSPECTS

The papers presented to the Conference have reviewed the properties and potentialities of a wide range of power producing reactors. This range probably included most of the reactor types reasonably feasible.

As Sir Christopher Hinton pointed out in his paper, P460, the United Kingdom is at present carrying out full scale experiments at the two ends of the scale of nuclear power reactor possibilities: the simple natural uranium graphite system (at Calder Hall), and the fast plutonium breeder (at Dounreay). Studies are also in progress on other systems which are thought to show promise, including in particular water-moderated types, as possible successors to the graphite-moderated types.

It would be difficult to sum up the present position as regards the desirability of the various technically practicable reactor types in a better way than by quoting a few paragraphs selected from Alvin M. Weinberg's "Survey of Fuel Cycles and Reactor Types" (P862):

"The development of nuclear power and of fossil hydrocarbon fuel both have this in common: there are a variety of possible fuels, a variety of devices in which they can be burned, and a variety of uses to which the energy can be put. Because the development of hydrocarbon fuel utilisation has been so gradual, it has hardly been necessary or even relevant to consider the comparative merits of coal, oil, or natural gas. Each is used where it is available; and practical economic considerations determine the relative usefulness of the fuels in each situation.

"Evenually, this will be the case with nuclear energy. Both raw materials, thorium and uranium, will be used; questions of relative advantage will be settled by experience. Because the nuclear fuels are so much less bulky than fossil fuels, it is unlikely in the long run that one fuel will prevail over another simply because of local availability.

"For countries which possess no diffusion plant facilities for re-enriching slightly used fuel, the problem of which system to start with is automatically answered: natural uranium must be the raw material. But this is a temporary situation. The plutonium produced in the natural uranium reactors will be burned in enriched reactors, and it soon becomes a question whether to use the excess neutrons to manufacture uranium 233 or to manufacture more plutonium 239.

100 FEASIBLE COMBINATIONS

"The enormous difficulty of choosing a proper path for reactor development is easily seen by estimating the number of conceivable reactor types. In Table IV are listed some of the choices which are more or less at the disposal of the reactor designer.

TABLE IV.—*Choices to be Made in Reactor Design*

Fuel	Fertile material	Neutron energy	Coolant	Geometry	Moderator
U233	Th	Fast	Gas	Hetero-geneous	H_2O
U235	U	Resonance	Liquid metal	Homo-geneous	D_2O
Pu239		Slow	H_2O D_2O Hydro-carbons etc.		Be BeO C etc.

Table IV by no means lists all possible choices; yet, the total number of combinations in Table IV is $3 \times 2 \times 3 \times 5 \times 2 \times 5 = 900$ possible reactors! Of course not all of these are sensible; for example, a fast reactor could hardly be cooled with H_2O. Even so, there are probably at least 100 combinations which are not obviously unfeasible. The central issue in reactor development is to trace out of this welter of possibilities the dozen or so which are most likely to succeed.

"Fortunately, nuclear considerations greatly reduce the number of possibilities. The slow neutron breeding cycle most certainly requires U233-Th; the fast neutron cycle can use either U233-Th or Pu239-U but the latter has the nuclear advantage.

"Will one or two reactors emerge as unique choices? I think every worker in reactor design must have wondered whether, in the long run, any one reactor type will emerge as so distinctly superior to the others that it will render the rest obsolete. The history of hydrocarbon-burning devices suggests that the technology will develop a succession of "most desirable" types; the reciprocating steam engine was followed by the steam turbine—which may ultimately be replaced by the gas turbine. Within each class—say the steam turbine—there has been a tremendous development and corresponding high rate of obsolescence; for example, the heat rate of the most modern turbines is less than half the heat rate of turbines only 20 years old.

"But the main reason for obsolescence of conventional power generating devices—low thermal efficiency—will hardly operate to render nuclear power plants obsolete. Rather nuclear plants ought to be much more like hydroelectric plants: if they have sufficiently low over-all operating costs, and this is a sum of costs determined by thermodynamic efficiency, material efficiency, maintenance, etc., then it is at least not obvious why they should become obsolete any more than dams become obsolete.

"If all else is equal, that reactor plant is best which operates at the highest thermal efficiency. However, since in each reactor there is always held up a significant amount of expensive material—either fissionable material or moderator—and this held-up material represents a continuing expense, it is also important to extract as much energy from a given amount of fuel as possible. The electrical energy extracted per unit amount of fuel or expensive moderator might be called the 'material efficiency.' In a chain reactor high material efficiency, as well as high thermal efficiency, leads to low over-all power cost.

THE BEST REACTOR?

"What I have said refers mostly to the long run. In the meantime, with highly enriched material something of a rarity, it is inevitable that power will be extracted from the natural uranium systems in more or less conventional reactors. Yet once a reactor is constructed with natural-uranium fuel rods, there will be a strong nuclear incentive, after the first few loadings with ordinary uranium, to switch to the U233-Th cycle. The strong possibility, even in the heterogeneous system, of making the U233-Th thermal system self-sustaining will always be an attractive goal, no matter how plentiful natural uranium may be. Thus it may not really be relevant to argue whether breeders ought to be developed as soon as possible. It seems to me entirely likely that most heterogeneous power reactors which begin their lives as thermal, natural-uranium converters will gradually convert to the U233-Th cycle simply because operation with this fuel is probably independent of raw material.

"In any event certainly two nuclear types, the slow cycle based on U233-Th and the fast cycle based on Pu239-U will become accepted reactor types. Beyond this—whether the reactors will be homogeneous or heterogeneous, whether the moderator ultimately will be D_2O, Be, C, etc., what the coolant will be—these are difficult issues whose outcome no one can foresee. It is of great advantage to our budding technology that it is being pursued—with such little overlapping—in so many different countries, for only out of such diversity in effort will come the answer to the question: 'Which reactor type is best?'".

Editor's Note: Certain of the reactors discussed in this article have been covered in greater detail in earlier issues of ENGINEERING; in terms of the reference figures of Table II these are: (1) the U.K. Calder Hall reactors (vol. 177, page 313, 1954, and vol. 179, page 240, 1955); (5) Russian atomic power station (vol. 180, pages 228 and 233, 1955); (18) BER-III, U.S. boiling-water reactor (vol. 180, page 228, 1955); (29) Dounreay fast breeder reactor (vol. 180, page 280, 1955). In addition a number of reactor systems suitable for power production were outlined in the issue of August 26 on page 282 (1955).

DESIGN IMPROVED BY STUDY OF SERVICE CONDITIONS

Economic Construction of Runways

Substantial economies in runway construction may be possible as a result of studies carried out by the Institute of Transportation and Traffic Engineering of the University of California. In a lecture given in London before the Airport Engineering Division of the Institution of Civil Engineers, Assistant Professor John Hugh Jones, M.S., A.M.Amer.Soc.C.E., of the University of California, described investigations on the transverse distribution of air traffic on runways and how the results could be used to design a runway pavement of varying thickness instead of the uniform thickness which is common practice.

Observations of the skid marks on runways demonstrate that the traffic is fairly well centred. To determine the actual transverse distribution, studies were made at Los Angeles, Oakland and San Francisco airports using electrical traffic-detector tapes capable of determining the transverse position of a wheel to within 10 ft. at three locations on the runway—600, 1,000 and 1,800 ft. from the runway threshold. The runway widths were between 150 and 200 ft. At each airport, both night and daytime movements, under both visual and instrument conditions, were observed for all transport aircraft—taking-off and landing.

The results showed that, at the three locations, the traffic was concentrated within a 60 ft. width of runway, less than 5 per cent. of the traffic occurring beyond these limits. The maximum percentage of wheel-load applications in a 10 ft. section of detector tape occurred at Los Angeles airport, 600 ft. from the end of the runway and amounted to 28 per cent. of the total number of wheel loads recorded at this location. The patterns for all the locations for the three different airports were quite similar, indicating that the transverse distribution of wheel loads is approximately the same all along the runway.

From an average distribution, representing all the observations, it was concluded that the pavement for the central 60 ft. portion of a runway could be designed for 25 per cent. of the total number of wheel applications which the runway would receive during its economic life, the remainder would be designed for 3 per cent. of the wheel-load applications.

To give an idea of the saving in cost which might be effected by using a variable-thickness pavement section, the costs were estimated for a runway 200 ft. wide and 8,000 ft. long. With a uniform thickness of 36 in., the cost was calculated to be 724,000 dols.; with a thickness of 36 in. in the central 60 ft. and 30 in. in the remaining 140 ft., the corresponding cost was 621,000 dols.

Professor Jones also described another investigation carried out by the Institute on suitable radii for "lead-off" taxiways—i.e., ways which would permit landing aircraft to leave the runway at speeds as high as 50 m.p.h. Tests were carried out on Douglas DG-3 and DC-6 and Convair 340 aircraft to correlate turning radius with the limiting speed of impending skid. It was found that the type of landing gear and the size of aircraft had no effect on the speed/radius relation; for a given type of surface, only speed was significant in deciding the limiting radius of turn. For a dry bituminous surface, suggested figures for the speed/radius relationship were as follows :—

Speed, m.p.h.	10	20	30	40	50
Radius, ft. ..	50	150	350	650	1,000

Other investigations are now in progress on the location of lead-off taxiways and the determination of suitable widths for them.

UNDERSTANDING OF MECHANISMS AIDED BY WORKING MODELS

A SWISS SYSTEM FOR TEACHING AND DESIGN

The Swiss organisation, Miniatecnic, of Zürich, have published in *Miniatecnic News* of July, 1955, details of a range of precision-made models designed to illustrate the principles of kinematics and to be of use to designers, engineers, technicians and engineering students generally. There are two parts to the project: the kinematic models of mechanisms, and the scientific instruction book. The work has been done in association with Professor Heinrich Brandenberger, of the Swiss Federal Institute of Technology, author of *Toleranzen Passung und Konstruktion*.

The Miniatecnic publication contains not only a complete list of the first range of models, with prices, but also a philosophy for designers and arguments for the teaching of kinematics, using the models, in technical colleges and other instructional institutions. As a well conceived and thoroughly prepared presentation of the case, the publication must rank high in engineering and technical literature.

It was originally intended to develop a universal construction set which would enable the owner to build various mechanisms by selecting the appropriate components. One hesitates to mention the word Meccano, but the early plan seems to have been the production of high-grade sets of components with that kind of constructional purpose in view. This plan proved impracticable because of the very large number of components involved—it is stated to be more than 1,600 for 50 models—and the alternative adopted is to use common parts for a limited series of about 12 models. For example, the first set of components will enable the following mechanisms to be built: four-bar linkage; crank and rocker mechanism; drag-link mechanism; reciprocating double-crank mechanism; parallel-crank mechanism; anti-parallel crank mechanism; rotating-block linkage; gear transmission; Watts' planetary gear; cross-slider crank mechanism; cam mechanism; and Maltese Cross mechanism.

The models are evidently made to scientific instrument standards, most of the parts having tolerances of 0·01 mm. (0·00039 in.). They therefore meet the requirements that the motion transmitted shall be perfect and not affected by backlash or shake. The instruction books are compiled on the loose-leaf principle and contain drawings and diagrams of the linkages with some discussion of the kinematic principles involved.

As to the desirability of using models (in place of diagrams or film strips), the case is well argued in the publication. It is, of course, possible to regard kinematics as a branch of geometry, but the subject is likely to have a greater appeal to the young engineer if he can actually handle the mechanisms and discover their peculiar features by manipulation. The famous collection of models by Reuleux, of the Berlin Engineering College, is referred to; these were compiled almost 90 years ago and, like Reuleux's classical treatise, have now only a museum interest. Few, however, would oppose on educational grounds the use of the Miniatecnic models. Anything which assists comprehension is now acceptable; and the models certainly do that. They are therefore likely to have their greatest appeal in technical colleges, for the benefit of young designers and draughtsmen; though they will certainly prove to be an acceptable adjunct to any drawing office concerned with the design of mechanisms.

The publication perhaps overstates the case for the teaching of kinematics on an adequate scale in technical colleges. Although so recommended by Professor Nagel, kinematics is unlikely to be dealt with as a subject apart and in its own right: college curricula are already overcrowded. The most that can be hoped for of the student in this country is a nodding acquaintance with the various mechanisms (greatly facilitated by the models) and the ability to deal in a fundamental way with the velocities, accelerations and forces arising in any given mechanism. But at a later stage, the designer can well afford to devote attention to the whole range of mechanisms, some of which he will most certainly have to incorporate in his designs. The Miniatecnic models will be a considerable help to him in extending and deepening his understanding.

The models and instruction book are obtainable from Miniatecnic, 15 Auf der Mauer, Zürich, Switzerland. Arrangements have been made for Unesco coupons to be used for purchases, if desired.

BRITISH ASSOCIATION MEETING AT BRISTOL

PAPERS BY YOUNG ENGINEERS

Concluded from page 452

Session B on Tuesday, September 6, was allocated to the reading and discussion of four papers by young engineers; one of the authors, however, was unable to attend. Professor Andrew Robertson, F.R.S., took the chair for the session and invited Mr. D. L. Brook to present his paper, which was entitled "The Effect of Leakage on Compression and Expansion in a Non-Flow Process," and dealt with the mass variation, due to leakage, in an engine cylinder during a motored cycle. We hope to reprint the paper in a later issue.

THE EFFECT OF LEAKAGE IN AN ENGINE CYLINDER

Professor A. F. Burstall, the first speaker in the discussion, said he wished to congratulate the author on the work he had done during the past year and to explain a little more fully the reasons for doing it and the circumstances in which it was carried out. As part of his work as an honours student in his final year, Mr. Brook had been given a project in which it was desired to know the variation of mass in a leaking cylinder-piston combination. As far as he was aware that problem had not been elucidated before, and the only practical applications he had come across until recently were in connection with internal-combustion engines where there might be a groove in the cylinder wall or the piston rings had begun to stick; in which case the variation of mass was very small in comparison with the variation dealt with by Mr. Brook, where in the extreme case, the orifice being very large, the pressure fluctuations would also be very small.

The practical interest of the project was in connection with the Philips type of hot-air engine, one of which had been built at Newcastle. It was important to know what the mass of gas was in each of the cylinders at any particular instant, and a good deal of discussion of a theoretical nature had taken place before the work was attempted, which was in itself an attempt to show that some theories were right and others were not. One question he would like the author to answer concerned the effect of the jacket temperature on the leakage and another referred to one of the values of n which did not seem to have been very evident in the explanation given by the author. Presumably, γ should not have been n and it would be interesting to hear something about its value during compression and expansion.

In his reply, Mr. Brook said the γ would in fact not be γ, and the jacket temperature varied with the index of expansion and compression. He had put it down as γ to simplify matters but in his actual work he had used values of n obtained from books in various compression ranges and different temperatures. It had proved impossible to calculate what the value of n should be, and having made some experiments using the cylinder completely blocked-up and getting negligible results he had used the values given in text-books.

Mr. K. H. Griffin asked if an explanation could be given regarding the discrepancy of the theoretical results. Was it a fact that under the experimental conditions the assumptions made in using the equations had not been brought out fully? In his reply Mr. Brook said that actually, with the heating effect n would be greater than γ on the suction side; 1·42 was the value used and it was not enough, but as it was given in text-books he had used it. Mr. T. Ginty said it appeared that the experimental inlet stroke was a little greater than the theoretical and he wondered if that could be explained by a small time-lag in the pick-up system. Mr. Brook replied that this was practically negligible.

This completed the discussion and the chairman, in proposing a vote of thanks to the author, said the paper was an excellent illustration of the kind of work being done at Newcastle. From past experience with students he knew how difficult it was for them to find time to write up the experiments, and the hard work put into the paper by the author was greatly appreciated. The vote of thanks was duly accorded.

The next paper on the programme was one by Mr. S. Henderson, B.Sc., Ph.D., on "Collapse Tests of Vierendeel Trusses," but the author was prevented from attending the meeting on account of an Air Ministry ruling in connection with trainee R.A.F. officers. The paper will, however, be published in a subsequent issue of ENGINEERING.

CONSTRAINT EFFECT IN BOX BEAMS

A joint paper by Mr. D. Howe and Mr. K. H. Griffin on "Constraint Effects in Box Beams" was then taken. The paper, which will be reprinted in ENGINEERING later, surveyed the modifications to elementary stress distributions near built-in ends and points of concentrated load, with particular reference to swept-wing structures.

In opening the discussion on this paper, Mr. T. Ginty said he had no doubt that the constraint effect had been investigated before and he imagined that in aircraft construction it had been got over by using larger safety factors and therefore heavier construction. He wondered whether the knowledge which the authors had now imparted would lead to a reduction in the weight of the aircraft wing.

Mr. Griffin, in reply, said constraint effects were first investigated in 1926, which was about the time that box beams came to be used in aircraft structures, so that they had been known and allowed for. He was afraid therefore that there would be very little reduction in weight. Aircraft designers did not actually work to safety factors but had an ultimate load factor of 1·5 which had to cover such items as manufacturing discrepancies and fatigue effects, although, of course, in civil air lines extra allowance was made for the latter.

Professor Burstall asked whether any allowance was made for constraint effects in box-type

cantilevers which were used for poles supporting conducting wires, as well as for cranes and other mechanical constructions in which he believed box-type beams were used considerably. Mr. Griffin, in reply, said he was not an expert on that side of the subject, but he had looked round in order to try to find examples of box beams in what might be termed "real" engineering. They were commonly deep box beams, an example being the Britannia Bridge. Mr. Howe, who also replied to Professor Burstall, said that in the sort of box beams that civil engineers would use the top and bottom skins were relatively thicker and the distances the shear had to carry across to build up the direct stresses were smaller.

This completed the discussion on the paper and on the motion of the chairman a vote of thanks was accorded to the authors.

STRESS DISTRIBUTION UNDER FOUNDATIONS

A paper entitled "A Mathematical and Photo-elastic Investigation of Stress Distribution under Foundations" was then presented by the author, Dr. J. E. Gibson, lecturer in civil engineering at Glasgow University. The paper, which will be reprinted in ENGINEERING shortly, gave a mathematical investigation for a two-dimensional elastic foundation, followed by three-dimensional experimental tests. In these tests use was made of a composite block containing a plate of stress-optically sensitive material.

The delivery of the paper was followed by a discussion in which Dr. Gibson, replying to a question by Mr. D. Howe, said the photo-elastic material cemented into the block on which the foundation rested was of similar elastic properties, as it was essential to preserve elastic homogeneity.

Sir Richard Southwell, F.R.S., said he had attended a plasticity symposium in Brussels last year, and Professor Hetenyi, from North Western University, Illinois, had spoken about a new plastic which would behave like a plastic material and still had photo-elastic properties. The hope was therefore that it could be used to solve not only elastic problems but also the more difficult plastic problems. It would be interesting to know whether that material had come into use during the last year. Dr. Gibson replied that he had not yet come across it.

To a question raised by another speaker, Dr. Gibson replied that he did not wish to come up against the soil mechanics experts; the analysis he had put forward could only apply to an elastic soil. He had found out from the soil mechanics people that they used the ordinary Boussinesq stress distribution to determine the bearing stresses. That being so and if they were prepared to use elastic conditions his method was slightly in advance; but, of course, its application was to a two-dimensional system. The three-dimensional case would probably not be very difficult to deal with; he did not see why the method should not apply to runways.

The last speaker in the discussion asked if there were any possibility of extending the photo-elastic technique to systems possessing cylindrical symmetry, such as pillars, and Dr. Gibson replied that he saw no reason why it should not be so extended.

The chairman then proposed a vote of thanks to Dr. Gibson for his paper, which was duly accorded.

SNOWY MOUNTAINS HYDRO-ELECTRIC PROJECT IN AUSTRALIA

To take the place of Mr. Henderson's paper, a film on the "Snowy Mountains Project, Australia," was shown and explained by Dr. R. L. Aston, of the University of Sydney, who is consultant for surveys to the Snowy Mountains Hydro-Electric Authority. Dr. Aston attended the Bristol meeting as a representative of the Australian and New Zealand Association for the Advancement of Science.

Introducing the film he said the Snowy Mountains formed the highest mountain range in Australia, rising to 6,000 ft. in many places and in some places to over 7,000 ft. It was frequently referred to as the Australian Alps. The Authority was constituted in 1949, by the Governments of the Commonwealth of Australia and of the States of New South Wales and Victoria. The estimated cost of the scheme (as based upon the first of its major competitive tenders for section contracts, 1949) is £442 million, and the total expenditure up to June, 1955, has been £63 million. The amount budgetted for the year 1955–56 is £14,600,000. The scheme is to supply 3,070 MW of power, sold at a rate to meet the whole cost of the scheme, and also to increase the water at present available for irrigation in S.E. Australia by 1,818,000 acre-feet a year.

Aqueducts, dams, tunnels and power stations are being constructed over a mountainous region measuring 100 miles in a north-south direction by 40 miles east-west. Previously there were no major roads or townships in this region which is situated about 50 miles from Canberra and about 200 miles from both Melbourne and Sydney. The scheme involves the construction of seven major dams, 17 power stations (mostly underground), 83 miles of tunnels and over 300 miles of aqueducts. The fall from the highest reservoir to the final power station is about 4,000 ft. The Authority employs over 600 professional engineers and other technical survey staff, but because of the shortage of professional engineers in Australia many major sections of design are being carried out by the United States Bureau of Reclamation and some by contractors. The authority has built accommodation for 4,000 persons to provide for employees and their families.

MAPPING THE REGION

An increase in the rate of interest from 3½ to 4½ per cent. since the initial design of the scheme, increased operating costs by 40 per cent. Improvements in integrated system design, however, have increased the guaranteed energy output by 50 per cent. of the capacity of the scheme initially approved. "Investigation" is accounting for an exceptionally high proportion of the cost. Base maps for the whole region are being produced by triangulation and air-survey; 600 miles of precise levelling have been completed in rugged country. As an indicition of the precision of this work it was mentioned that in one circuit of 103·2 miles with a rise-and-fall of 13,275 ft. the misclose was only 0·0002 ft.

In the course of the work extensive novel developments in hydrology have been required and achieved. Geological exploration of the whole region has also been carried out and this has necessitated extensive drilling to depths up to 2,000 ft. The conservation of alpine soils under Australian conditions has been a new and difficult problem but such problems have been dealt with by a large scientific services division.

The progress and present state of the work was effectively illustrated by the film which might well be shown to a larger audience. The showing of the film completed the work of the session and also completed the programme of Section G for the Bristol meeting.

FUTURE MEETINGS

The annual meeting of the Association is to be held next year in Sheffield, from August 29 to September 5, and Sir Raymond Priestley has been elected President. In 1957, the meeting will be held in Dublin, and the General Committee have received and accepted an invitation from the City and University of Glasgow to hold the 1958 meeting in that City.

ELECTRICITY SUPPLY IN HOLLAND

I.E.E. VISIT TO RESEARCH LABORATORY AND POWER STATION

A party of some 130 members of the Supply Section of the Institution of Electrical Engineers, with their ladies, visited Holland under the chairmanship of the Section (Mr. J. D. Peattie) from Thursday, September 8, to Monday, September 12. They were able to see what is being done in a number of fields of electrical research and testing at the Arnhem laboratories of Kema, as well as to gain an idea of modern power station practice at Amsterdam. They were also given facilities for inspecting the maintenance work carried out on aircraft by the Royal Dutch Air Lines at Schipol airport, and incidentally to appreciate the smooth operation of the electric railways in Holland.

KEMA RESEARCH LABORATORIES

The outstanding event of the visit was the inspection of the laboratories of the N.V. tot Keuring Van Electrotechnische Materialen (Kema) at Arnhem, where a day was spent.

This establishment was founded in 1927 when the then electricity supply undertakings of the Netherlands recognised the need for a common organisation to carry out tests and researches on electrical matters. An estate "Den Brink" was gradually acquired in the town from 1931 onwards and Kema now carries on its work in a well laid-out park, covering some 50 acres. In 1938 new laboratories and other buildings were inaugurated by H.R.H. Prince Bernhard, but thereafter work was drastically interrupted by the war when much material damage was caused and all the equipment was removed by the enemy.

These disabilities however, have now, been overcome and the park at present contains 18 buildings, which include laboratories for high-voltage, general and physical and chemical work. There is also a group of four buildings, in which short-circuit tests on switchgear and other equipment are carried out.

SHORT-CIRCUIT TESTING

The "short-circuiting" laboratory is provided with facilities for alternating-current testing up to 1,200 MVA at 100 kV three-phase or 200 kV single-phase. Direct-current testing can also be carried out with currents up to 37,000 amperes at 800 volts and up to 18,500 amperes at 1,600 volts.

The equipment in the machine room, of which a view is given in Fig. 1, consists of two three-phase synchronous alternators, each of which is driven by a 1,000 kW asynchronous motor at a speed of 3,000 r.p.m. The alternators have two stator windings per phase, which can be connected to give voltages of either 11, 6·5, 5·5 or 3·2 kV. To supply the super-excitation necessary for breaking tests and combined making and breaking tests, two sets have been installed, which can be seen in the background of Fig. 1. Each set comprises two direct-current generators, both of which are capable of delivering up to 10,000 amperes at 800 volts for a short time. The inertia of the sets is increased by three flywheels and an asynchronous motor is provided for driving. These sets are also used for direct-current testing.

The machine building also houses two banks of three single-phase transformers for raising the test voltage. The secondary windings of these transformers are arranged so that a series of voltages up to the limits mentioned above can be obtained. Other equipment comprises reactors for current regulation, capacitors for controlling the re-striking voltage, a making switch and two air-blast master switches. The machine room is connected with a two-cell test bay, which can be observed through rectangular windows in a separate control building. This contains a pendulum for timing all the operations during a test, a 12-element electromagnetic oscillograph, a cathode-ray oscillograph and a restriking voltage indicator. Tests are carried out on equipment sent in from

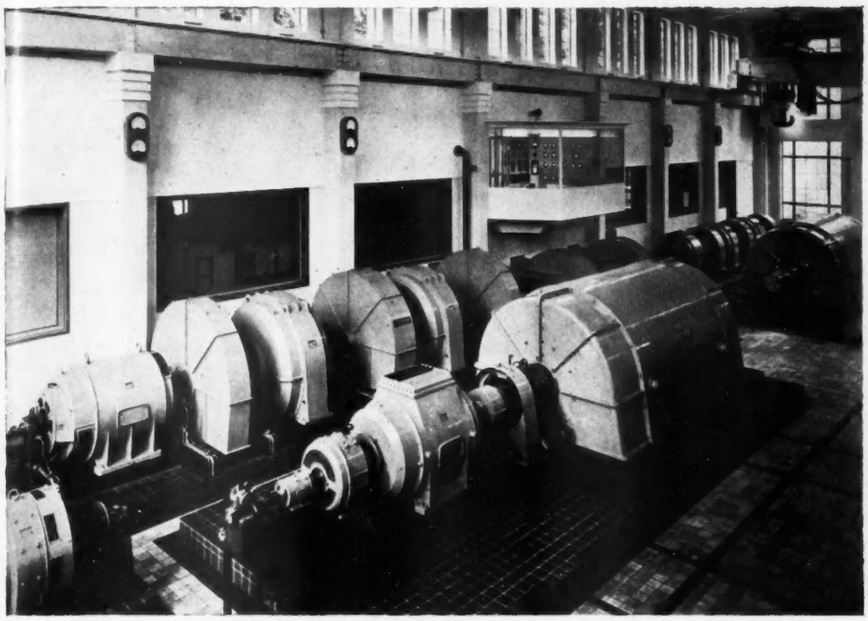


Fig. 1 Machine room in the short-circuit laboratory of the Kema Research Establishment, Arnhem.

most countries in Western Europe, including the United Kingdom, and certificates of performance are issued.

HIGH-VOLTAGE LABORATORY

The high-voltage laboratory, the interior of which can be seen in Fig. 2, is equipped for alternating-current tests up to 525 kV, for impulse tests up to 2,700 kV and a current of 35,000 amperes and for direct-current tests up to 400 kV. The equipment comprises three main testing transformers, two impulse generators, a special direct-alternating current set for producing direct current during load-cycle tests on high-voltage cables, current sources for vibration tests on overhead lines, and a complete range of testing transformers and measuring instruments. Tests on buried cables and investigations on short experimental overhead lines are carried out on a lawn outside the building, while at the present time attention is also being paid to stability tests on high-voltage cables, ionisation in organic detectors, impulse tests on transformers and the co-ordination of insulation.

The general laboratory is divided into a number of departments in which tests and investigations on all kinds of electrical equipment, which do not require a very large power or voltage, are made. The apparatus dealt with includes all types of accessories, cooking, heating and other domestic appliances, lamps and lighting fittings, batteries and electronic devices of many kinds. There are also laboratories in which motors, apparatus using large currents at low voltages, and electric furnaces are tested.

In the chemical laboratory, tests are carried out on solid and liquid fuel and combustion problems are investigated, while examinations are also made on insulating and lubricating oil, water and metals and their alloys. A special room is devoted to work on oil, and on steam and water under very high pressure.

Recently, physical research work has been concentrated on nuclear problems of different kinds, including the influence of neutrons and fission products on solids. The particles required for this purpose are produced in a 600 kV direct-current cascade generator. Other fields of investigation include an examination of the physical mechanism of the electrical breakdown of solids, of heavy current arcs, such as are produced in high-power circuit-breakers, and of the visibility of light of low intensity.

Considerable interest was shown in a prototype reactor of the homogeneous suspension type which was exhibited at the recent Geneva conference and is the Dutch contribution to the solution of the problem of generating electricity from nuclear energy.

ELECTRICITY SUPPLY CONTROL CENTRE

A visit was also paid to the control centre of the main Dutch electricity supply network, which is situated in the same park as the Kema laboratories. This is operated by a limited company known as N.V. Samenwerkende Electriciteits-Productiebedrijven (SEP) and is connected by a telephone system with the regional centres of the partner supply companies. The arrangement is that these companies operate the various power stations, substations and lines in their areas under the general control of SEP, which is, in turn, primarily concerned to see that interchange arrangements, both with the constituent companies and with foreign concerns in Germany and Belgium, are adhered to. Normally, it only gives such directions to the local centres as are required by deviations from the pre-arranged programme of energy exchange and adjustment of the system voltage and frequency. In the event of a breakdown, however, it decides how its effects can be limited and where relief can be found.

The control centre is equipped with mimic diagrams of the 150 kV and 110 kV grids, the condition of the lines, transformers and busbars being shown by lamps. Meters are provided to record the system voltage and frequency, as well as the output of each portion, the exchanges between the national system and neighbouring foreign systems and between the partners themselves.

At the conclusion of these inspections the party visited the Airborne Cemetery at Oosterbeek-Hoog where many of those members of the British and Allied Forces who died in the course of the great airborne operation of September, 1944, are buried. Here a simple, but impressive, wreath-laying ceremony was carried out by the chairman and those present were able to pay their tribute to the care which is expended on the upkeep of a worthy memorial.

GENERATION AT AMSTERDAM

On the morning of September 10, a visit was paid to the Hemweg power station in the western dock area of Amsterdam. This station, which was begun after the 1939–45 war and commissioned in 1953, was initially designed for an installed capacity of 220 MW, but there is room for an extension of a similar size.

The plant consists of eight double-flow pulverised-fuel fired boilers with a maximum continuous output of 120 tons of steam per hour; these are arranged in pairs so that with a 55 MW turbo-alternator they form entirely separate units. It is the third station to be built in Amsterdam, the first being opened in the eastern end of the town with a capacity of 3,800 kW in 1903 and the second in 1918 with an initial capacity of 54 MW, which has been gradually increased to 225 MW.

The Hemweg station forms an important link in the electricity supply of the Netherlands, which, owing to the nature of the country, is exclusively obtained from thermal plant. Generation of power is almost entirely concentrated in ten stations, or combinations of stations, which are owned directly or indirectly by seven provinces and cities. As a result of negotiations started shortly before the war the larger stations are now connected by a 150 kV grid in the south-western part of the country and by a 110 kV grid in the north-eastern part. These two systems are connected by a 150 kV system running from Nijmegen to Deventer via Appledoorn. The Hague and Rotterdam are connected by four single-core oil-filled cables, but elsewhere double-circuit overhead lines are used. When completed the grid will comprise three inter-connected double-circuit rings, each 150 kV circuit being capable of transmitting 100 MVA and each 110 kV circuit 50 MVA.

The medium-sized stations such as those at Haarlem, Delft and Gouda are connected to the main grid by 25 kV cables or 50 kV overhead lines. Overall operational control is effected from Arnhem.

Fig. 2 A view inside the high voltage laboratory at Arnhem.

Fig. 1 The Admiralty test house, used for proving main-propulsion and auxiliary gas turbines up to 10,000 s.h.p. for naval use.

NATIONAL GAS TURBINE ESTABLISHMENT

(1) TEST FACILITIES

When the National Gas Turbine Establishment was set up in 1946 it inherited a small amount of test facilities from its forebears, the engine department of the Royal Aircraft Establishment, and Power Jets (Research and Development), Limited, the main items of which were a 4,000 h.p. motor-driven air-compressor set at Pyestock for combustion and gas-turbine work, and a 6,000 h.p. steam turbine at Whetstone to provide shaft power for compressor testing. Both these pieces of plant have been, and still are, of great value. A full description of the 6,000 h.p. compressor rig at Whetstone appeared in the July 2, 1948, issue of ENGINEERING (vol. 166). Since publication of this article, however, two major modifications have been carried out. The plant for testing turbine rotors has been removed from the atmospheric compartment, which is now equipped for testing compressors. Thus the steam turbine is now employed to drive compressors at either end. An activated alumina bed has also been provided to remove moisture from the air being passed to the altitude chamber. Since 1946 additional plant has been steadily added, and almost without exception this development has taken place at Pyestock, with the object of concentrating the main resources of the Establishment on this site.

The original 4,000 h.p. air-compressor set in the compressor house was duplicated, and an additional compressor set operating at a higher pressure was added. A range of high-speed gearboxes was provided which enabled experimental compressors to be tested by taking the drive from the original motor. The air supplies from the compressor house were augmented by a battery of five jet engines from which air is bled. All the air is piped into test cubicles adjacent to the compressor house. Air is also supplied to the nearby fuel and power laboratory in which work on coal burning as applied to gas turbines is carried out. Tests requiring a suction supply to simulate reduced atmospheric pressures at high altitudes take place in cubicles fitted with ejectors. Here the air from the compressor house is passed through liquid-fuel-fired preheaters with water added to produce a fluid of mixed products of combustion and steam which work the ejectors.

With the exception of the fuel and power laboratory, all these additional facilities were installed in existing buildings, or extensions to them, on what is now the old part of the Pyestock site. The need for still larger test facilities to match the rapid development of the gas turbine meant that new buildings and more test plant had to be provided, and so a larger group of buildings was erected on an adjoining site at Pyestock.

The largest of the new buildings, the plant house (Fig. 2), contains two 9,000-h.p. motor-driven compressors which, with an air-bleed gas-turbine set, provide compressed air for tests in a number of large combustion and aerodynamic test cubicles. The two motor-driven sets can also operate as exhausters for giving sub-atmospheric conditions in the test cubicles. Nearby is a compressor and turbine test house, known as the Battle test house, because its boilers were taken from an uncompleted "Battle" class destroyer. Steam from the boilers drives a 15,000 h.p. high-speed steam turbine, which is similar to the smaller plant at Whetstone, and supplies the shaft power needed for compressor testing. Air mains interconnect the compressor and gas-turbine test-beds in this building with the machines in the plant house. Power to run the electrically-driven plant is supplied from a large sub-station which is connected at 33,000 volts to the Southern Electricity Board's system. A gas turbo-alternator set under construction in the power station (Fig. 4) which will feed into the Establishment's electrical system, whilst waste heat from the machine will be used to heat most of the buildings.

Also under construction is a facility for testing ram jets and aircraft engines at high forward speed. This plant will be supplied with compressed air from the plant house and the Battle test house. The air may be used to give a pressure supply in either of two large cylindrical test cells, or for working ejectors to give suction conditions to the engine on test. It is intended that this plant will be used extensively for work related to supersonic flight.

A 600 h.p. motor-driven high-speed rig has been put into use recently for overspeeding and bursting turbine and compressor rotors, in the dynamics laboratory.

Bulk liquid-fuel supplies brought in by road are delivered to a tank farm from which the various grades are fed to small pump houses serving each of the main test buildings.

In addition to the wide range of facilities available for research work and component testing, there are a number of conventional test beds on which complete engines can be tested under sea-level conditions. Noteworthy among these is the Admiralty test house (Fig. 1) in which gas turbines up to 10,000 s.h.p. for marine propulsion, together with gas turbo-alternator sets, can be endurance-tested under conditions approaching those met with in service. This test house was described in detail in the March 27, 1953, issue of ENGINEERING (vol. 175).

Cooling water for test plant is drawn from the nearby Basingstoke Canal and from the Mid-Wessex Water Company's mains. Water is stored in two large circular reinforced-concrete

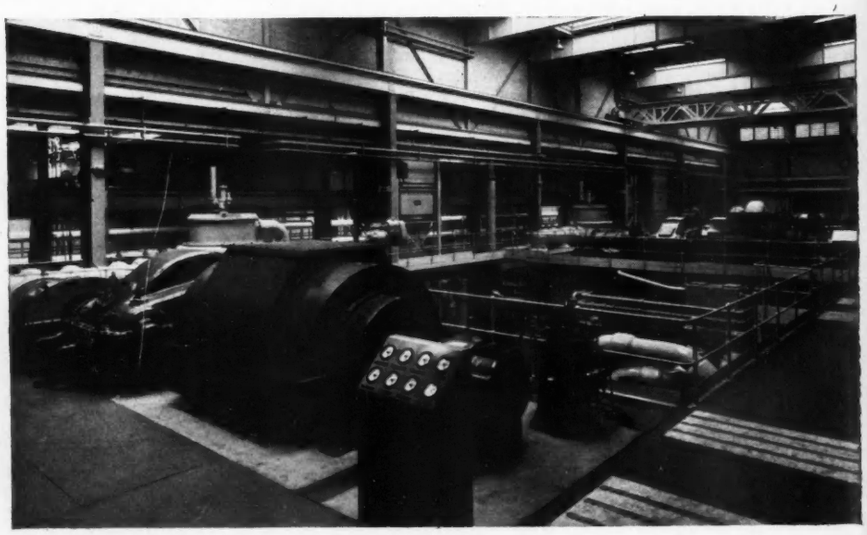


Fig. 2 The plant house; the main compressor plant consists of two Metropolitan-Vickers axial-flow compressors, electrically driven, each capable of delivering 60 lb. of air per second at 74·8 lb. per square inch gauge. In the background is a Parsons air-bleed gas turbine capable of delivering 25 lb. of air per second at a pressure of 44·8 lb. per square inch.

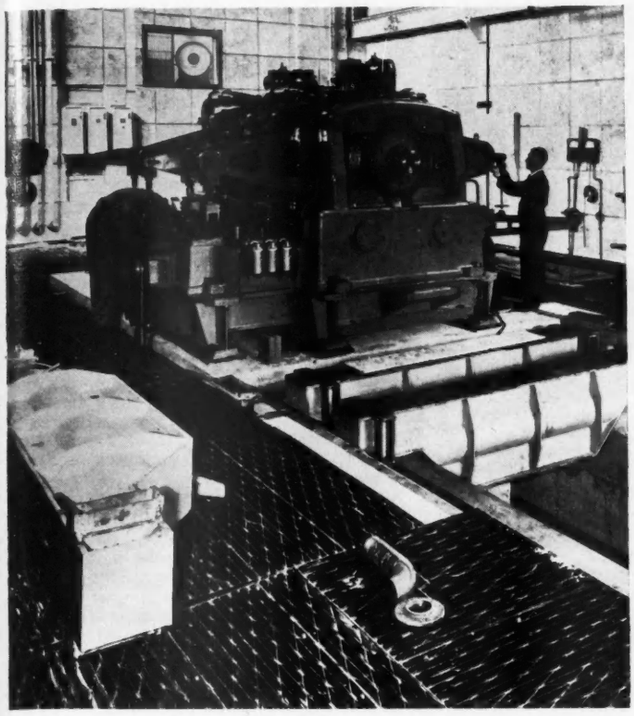


Fig. 3 The 25,000 h.p. Heenan and Froude dynamometer installed in the Battle test house will be used for turbine tests.

reservoirs and, wherever possible, is recirculated through induced-draught cooling towers.

COMPRESSOR HOUSE

The compressors installed in the old compressor house fall into three groups, of different delivery pressure, namely: 30, 45 and 135 lb. per square inch gauge. Air in the first group is supplied by a 600 h.p. motor-driven Howden-Lysholm compressor, which works on the rotary screw principle. Running at a constant speed of 3,000 r.p.m., this machine is capable of delivering 6·6 lb. of air per second at a constant temperature of 100 deg. C.

Air at a pressure of 45 lb. per square inch can be supplied by two compressors. One of these, a 4,000 h.p. British Thomson-Houston centrifugal type compressor, with four stages, is driven through a Ward Leonard variable-speed set, which makes possible a compressor speed range of from 3,500 to 7,000 r.p.m. A motor-generator set supplied at 6,600 volts alternating current generates a direct-current output for the driving motors. The maximum output of this compressor at the design pressure ratio is 26 lb. of air per second. The machine is uncooled, but air may be passed through an aftercooler to reduce its temperature from 190 deg. to 30 deg. C. if desired.

The second machine in this group is a Demag four-stage uncooled centrifugal compressor, driven through gears by a 4,000 h.p. slip-ring induction motor, with a speed range of from 3,750 to 5,100 r.p.m., which is obtained by the use of a liquid resistance. The designed output of the compressor is 29 lb. of air per second. The delivered air may be cooled from 190 deg. to 30 deg. C. by an aftercooler.

Air at the maximum pressure of 135 lb. per square inch is supplied by a Demag nine-stage centrifugal compressor which may be run at any speed between 4,900 and 7,000 r.p.m. This machine is fitted with an intercooler and aftercooler, and at the designed pressure ratio delivers 10 lb. of air per second at a constant temperature of 25 deg. C.

The two Demag compressors are driven from the same double-ended motor, which is coupled, by means of clutches, to whichever compressor is required. Hence it is possible to run only one of these compressors at any one time.

In addition, air at a pressure of 45 lb. per square inch gauge can be supplied by five modified Rolls-Royce Nene air-bleed gas-turbine engines, situated outside the building. The nozzle guide vanes on these aircraft jet engines have been modified so that 12 lb. of air per second may be bled off each machine. This air is fed into the compressor house 45 lb. per square inch air main, to boost the air flow at this pressure up to a maximum of approximately 115 lb. per second of air.

Test rigs may also be exhausted by ejectors, driven by air supplied by the compressor plant. Four of these ejectors are installed in the cubicles, the largest being capable of exhausting 12 lb. of air per second. Two 90 h.p. Holland rotary exhausters are provided for auxiliary exhausting duties. These machines, running at a constant speed of 585 r.p.m., are each capable of exhausting 2·5 lb. per second of air. To protect the machines, the hot exhaust gases are cooled to 40 deg. C. before passing through the exhauster.

Water for plant and test cooling is pumped at the rate of 186,000 gallons per hour and is recirculated after being cooled in an induced-draught cooling tower. In addition, 37,200 gallons of water per hour may be injected into hot exhaust streams, to reduce the temperature of the gases and to inhibit explosion.

Installed in the compressor house is a 4,000 h.p. rig, used for driving experimental compressors under test. The compressor to be tested is driven by the British Thomson-Houston compressor motor through primary and secondary step-up double-helical gearing. The secondary gearbox may be easily removed, and replaced by a gearbox of different ratio, so that, by fitting the required gearbox and adjusting the motor speed, the compressor may be driven at any speed up to 14,010 r.p.m.

FUEL AND POWER LABORATORY

The fuel and power laboratory, built to facilitate research on coal-burning combustion chambers and associated plant, is divided into two main sections: the coal-preparation room and the laboratory in which combustion testing is carried out.

The British Rema plant installed in the preparation room delivers either granulated or powdered coal at the rate of 1 ton per hour. The coal is fed from one of four bunkers into a feed hopper, from where it is passed through a hammer mill to be crushed to a fineness of less than $\frac{1}{8}$ in. The granulated coal is then mechanically cleared of stones, and then fed through a dryer, and dryer cyclone, where hot air is employed to reduce the moisture content to less than 1 per cent. The coal is then fed into a 5 ton reserve capacity bin, ready for use in the laboratory.

If, however, powdered coal is required, the granulated coal leaving the dryer cyclone is passed through a ring-roll mill and classifier where it is finely pulverised before entering the reserve-capacity bin.

The granulated or powdered coal leaving this bin is fed, through an Avery "weigh-feeder," to a coal pump which forces the fuel into the combustion chamber under test. The coal pump consists essentially of a short cylindrical element, with axis vertical, which is motor driven through reduction gearing at a speed of 13 r.p.m. This element, which bears a resemblance to the revolving magazine of a repeating revolver, has a number of cylindrical ports drilled parallel to its axis. Coal is gravity-fed into these ports, and, as the cylindrical element revolves, each port in turn comes into line with a port in the pump casing which admits air at a pressure of 100 lb. per square inch to blow the charge of coal out of the element port, and into the combustion chamber. The capacity of this pump is 2 tons per hour, which is double the capacity of the coal preparation plant. The reserve-capacity bin, however, may be filled before testing is commenced, and thus fuel may be burned in the combustion chamber at the rate of 2 tons per hour for a period of approximately 5 hours.

PLANT HOUSE

The plant house, brought into operation last year, is similar in principle to the compressor house, but the improved facilities allow combustion and aerodynamic research to be carried out on a much larger scale.

The compressors, installed in a central plant hall, discharge into 24 in. diameter mains, which distribute the compressed air as required to test cubicles along two sides of the building.

The main compressor plant consists of two similar Metropolitan-Vickers motor-driven axial-flow compressor sets which may work independently or in parallel (Fig. 2). Each 17-stage compressor is driven through gears by an 8,850 h.p. three-phase 11kV auto-transformer-started salient-pole synchronous motor at a constant speed of 7,150 r.p.m. The combined weight of compressor, gearbox and motor is approximately 27·5 tons.

Each machine is capable of delivering 60 lb. of air per sec. at the maximum delivery pressure of 74·8 lb. per sq. in. gauge. An aftercooler is provided to reduce the air temperature from 250 deg. C. down to a minimum of 50 deg. C.

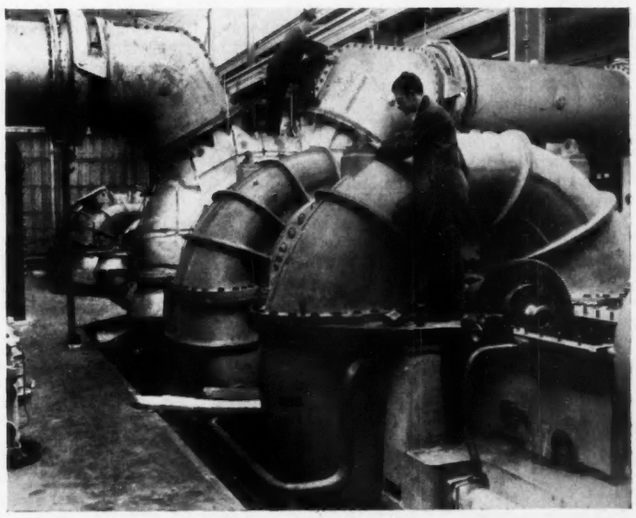


Fig. 4 The power station showing the low-pressure turbine and compressor of the 10,000 kW Parsons turbo-generator.

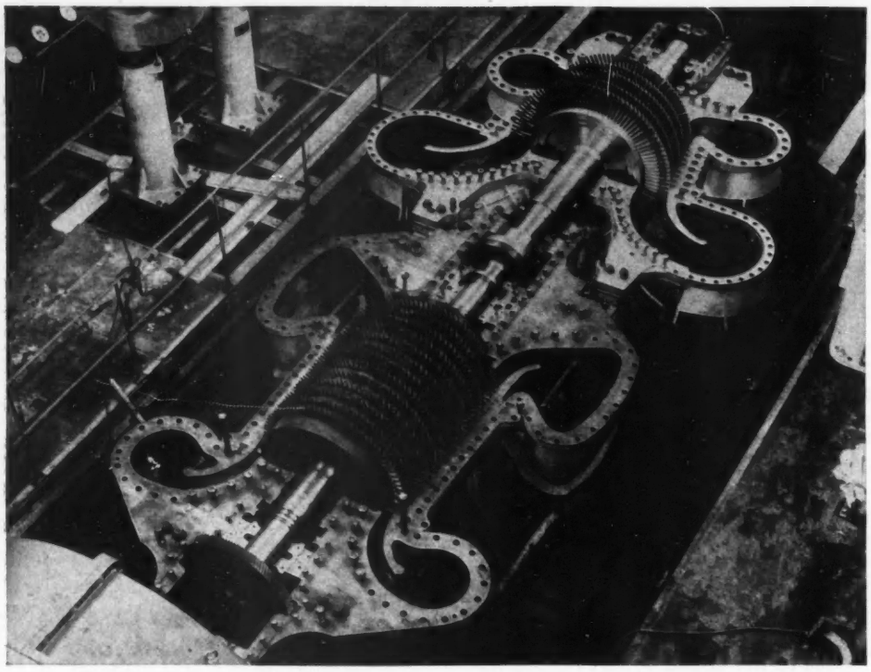


Fig. 5 The high-pressure compressor and turbine of the 10,000 kW Parsons turbo-generator with cover removed.

If, however, hot compressed air is required at the cubicles, the air is passed through the main pipework at a temperature of 250 deg. C. and may then be further heated to 400 deg. C. immediately before entering the test cubicle. This heating is carried out by means of an electric heater of 1,500 kW capacity, power for which is supplied by a Metropolitan-Vickers alternator set, comprising two 430volt three-phase 1,500 kW alternators, driven by an 11 kV synchronous motor through a double shaft extension.

The two motor-driven compressors may also be used to exhaust air, or the exhaust gases, from test equipment in the cubicles. When used as an exhauster, each machine will exhaust 8·62 lb. of air, per sec. the inlet pressure being 2·45 lb. per sq. in. absolute, and the outlet pressure atmospheric. To protect the machine, hot exhaust gases must be cooled before entering the exhauster, and this cooling is carried out in two stages. The gases are first passed through a gas cooler which is designed to cool the full duty of one exhauster from 1,000 deg. to 250 deg. C. at any pressure below atmospheric. At this reduced temperature, the gases are passed through 48 in. diameter pipework to the exhauster precooler, where they are further cooled to 50 deg. C. before entering the machine. The gases are then discharged through a silencing unit to atmosphere.

In addition to the two main exhauster-compressors, a Parsons air-bleed gas turbine has been installed to supply smaller quantities of compressed air for special duties. This turbine develops a s.h.p. of 9,470 when running at its maximum speed of 4,600 r.p.m. Of the 87·4 lb. of air per sec. passing through the compressor, 25 lb. of air per sec. are bled off into the 24 in. diameter pressure main. This air is delivered at a pressure of 44·8 lb. per sq. in. and a temperature of 191 deg. C., the latter being reduced when necessary by means of an aftercooler.

The large quantities of cooling water required are pumped through a 30 in. diameter water main, and returned to cooling towers working on the induced-draught system. One tower, operating with the gas coolers, has a flow of 240,000 gallons per hour with a temperature range of 86 deg. to 38 deg. C. The second tower is capable of reducing the temperature of 273,000 gallons per hour of plant cooling water from 42 deg. to 30 deg. C.

The test cubicles contain a total of 22 test-beds, which consist of reinforced concrete with broad flange joists in the top surface capable of absorbing a 90 ton load at 3 ft. 6 in. centre height. Take-off points on the air mains are provided opposite each test-bed, and from these points branch pipework is erected as required so that air may be supplied to, or gases exhausted from, the test equipment in the cubicles.

BATTLE TEST HOUSE

Plant in the Battle test-house like that of the 6,000 h.p. rig at Whetstone, is installed for the purpose of driving compressors under test, but here the available power is greater.

Two Yarrow-type boilers, similar to those fitted in H.M. destroyers of the "Battle" class, are each capable of an evaporation rate of 250,000 lb. per hour, at a pressure of 400 lb. per sq. in. and a temperature of 650 deg. F. This steam is used to drive a condensing steam turbine designed and supplied by Brush Electrical Engineering Company, to develop 15,000 h.p. when running at its maximum speed of 12,500 r.p.m. As at Whetstone, the combination of power and speed makes it necessary to work the turbine on a low vacuum, and employ reduced blade lengths which do not involve unduly high stresses. The turbine, of axial-flow type, with blading designed on the vortex-flow principle, drives at either end so that compressors of either rotation may be tested.

During test running, remote control is maintained from a control room outside the steam turbine compartment. In an emergency, the turbine may be hand tripped from any one of five positions, while automatic tripping follows the failure of turbine or compressor lubricating oil, failure of condenser vacuum or an undue rise in condenser water level, undue vibration of the compressor under test, or loss of compressor blade tip clearance. In the control room itself are the measuring instruments relating to the aerodynamic performance of the compressor; the purely mechanical aspects—bearing temperature, vibration amplitudes, etc.—are measured in a room below the control room.

The 25,000 b.h.p. Heenan and Froude dynamometer (Fig. 3) in a separate compartment will be used to brake gas turbines under test. During such testing, a large pressure drop through the turbine may be maintained by means of the exhauster/compressors in the plant house, which are connected to the Battle test house system by 48 in. diameter pipework. Water for condenser and plant cooling is circulated in a closed system, and cooled by means of concrete cooling towers working on the induced draught system.

GAS-TURBINE POWER STATION

The 10,000 kW gas-turbine power station has been built mainly for the purpose of studying problems associated with industrial applications of the gas turbine. The electricity generated will be consumed in the Establishment, and thus help to reduce the import of power from the grid during peak periods.

The power plant consists of a two-line open-cycle gas turbine, with intercoolers and heat exchangers, operating at an overall efficiency of 41 per cent. The gas-turbine unit consists of a low-pressure and high-pressure stage, the low-pressure turbine driving the 11-stage axial-flow compressor (Fig. 4) at 2,800 r.p.m., and the high-pressure turbine (Fig. 5) driving the 13-stage axial-flow high-pressure compressor and the alternator at 3,000 r.p.m.

Air enters the low-pressure compressor at the rate of 208·6 lb. per second, and is compressed to 2·57 times its original pressure. After passing through an intercooler, where the temperature is reduced from 119 deg. to 32 deg. C., the air passes through the high-pressure compressor where it is compressed to 5·5 times its original pressure, the temperature thus being raised to 119 deg. C. The air is now passed through an air/gas heat exchanger, where absorption of heat from the exhaust gases heats the air to 308 deg. C., before being fed into the combustion chambers.

Liquid fuel is burned in the combustion chambers, and the hot gases, at a temperature of 650 deg. C., pass to and drive the five-stage high-pressure axial-flow turbine. The gases then enter the three-stage axial-flow low-pressure turbine.

The exhaust gases then pass through the air/gas heat exchangers, and are either discharged to atmosphere or through waste heat exchangers to supply hot water for site-heating.

Also installed in this building is a 750 kW Daniel Adamson pass-out steam turbo-alternator, which is capable of supplying the power required for starting the 10,000 kW gas-turbine set. Steam is supplied from the Battle test-house boilers at a pressure of 390 lb. per square inch, and steam at a pressure of 60 lb. per square inch may be passed out of the turbine and fed into the calorifiers which supply the site-heating system as an alternative to the 10,000 kW set's waste-heat recovery system.

OVERSPEED AND BURSTING RIG

Overspeed testing is carried out both as a guide to stress calculation and for proving new designs. The rig consists of two 300h.p. 500volt direct-current motors in tandem driving, through a 13-to-1 step-up gearbox, a high speed shaft. This shaft projects into a substantial reinforced-concrete test cell, in which rotors up to 6 ft. in diameter and 10 ft. in length may be mounted for overspeeding or bursting. In the latter case, the rotor is surrounded by a lining of packed cardboard to minimise damage to the fragments.

The driving motors are supplied by a 500 kW grid-controlled rectifier fed from a six-phase 11 kV transformer. Speed control at low speeds is effected by altering the phase of the input to the grid of the rectifier, and at higher speeds by weakening the field of the motors. By these methods, adjustment of speed to within 60 r.p.m. is possible over the whole range up to the maximum of 47,000 r.p.m. True speed is measured by an electromagnetic pick-up on the shaft, the signal being displayed on a cathode-ray oscilloscope and compared for frequency with the trace from a standard oscillator.

The plant, which is remotely operated from a control room, is provided with dynamic braking equipment to assist in bringing the motors, gearbox and high-speed shaft (together with what remains of the rotor under test) quickly to rest.

Rotors which require high power to drive them, for example, complete axial compressor rotors, can be run in an evacuated casing.

STRESS DISTRIBUTION UNDER FOUNDATIONS*

MATHEMATICAL AND PHOTO-ELASTIC INVESTIGATION

By J. E. Gibson, M.SC., PH.D., A.M.I.C.E.†

The first study of the stress distribution in a semi-infinite medium was undertaken by Boussinesq[1] in 1885. In this investigation the nature of the stress distribution in a semi-infinite three-dimensional elastic medium, due to the application of an isolated force at a point on the boundary of the medium, was studied. The analogous two-dimensional case was first investigated by Flamant[5] in 1892. Since that time various authors have contributed to this field, notably A. E. H. Love,[9] S. D. Carothers,[2] M. Sadowsky[10] and L. N. G. Filon[4] who have considered plane-stress problems in plates subjected to various boundary loading conditions.

The first optical investigation of this nature was made by Carus Wilson,[3] who measured the relative retardation at points vertically under a load applied to a slab of glass resting on a flat base. More recently, Coker and Filon[4] and Frocht[6] have carried out a series of photo-elastic experiments on foundation problems. As far as can be ascertained, none of the above authors has considered the loading conditions that arise on the boundary of a semi-infinite medium due to the dispersion of the load through a foundation placed on the medium.

It is the aim of the first part of this paper to attempt to determine the nature of the boundary loading on a semi-infinite plane elastic medium due to a flexible foundation which is centrally point loaded. Having decided upon the nature of this loading, the author then determines the stress distribution that will result in the medium. This analysis utilises a method whereby the stress function is not explicitly derived but is used in its integral form to derive the required stresses; this greatly facilitates the solution of the problem.

The remaining part of the paper is devoted to a photo-elastic investigation of such foundation problems and a three-dimensional investigation is undertaken using a new photo-elastic technique. As the derived formulæ are for perfectly elastic plane media, their applications are limited in practice to the determination of the stress distribution under strip foundations resting on elastic soils, such as micaceous and diatomaceous silts.

THEORETICAL INVESTIGATION

When a point load acts normal to the boundary of a semi-infinite plane elastic medium, it may be shown that the stress distribution in the medium is satisfied by the following stress function:

$$\phi = -\frac{P}{\pi} r \sin\theta\,\theta \quad . \quad . \quad (1)$$

which yields, as it should from considerations of symmetry, purely radial stress in the medium.

Now the normal stress $\hat{y}y$ along any plane parallel to the boundary will be

$$\hat{y}y = \frac{\partial^2\phi}{\partial x^2} = -\frac{2P}{\pi}\frac{\cos^3\theta}{r} \quad . \quad . \quad (2)$$

(the directions of the stresses $\hat{y}y$, $\hat{x}x$ and $\hat{x}y$ are shown in Fig. 1).

Consider a very long foundation of depth a extending from $-\alpha$ to α carrying a central point load P and resting on a semi-infinite plane medium, as shown in Fig. 1. It is assumed that the foundation is perfectly elastic and that under loading its lower boundary remains in contact with the boundary of the medium. Provided that the elastic moduli of the foundation and the medium are of the same order, the normal stress distribution $\hat{y}y$ in the foundation along any plane parallel to its boundary will be assumed to be of the form given by equation (2) and thus at the lower boundary $y_1 = a$ will be

$$\hat{y}y = -\frac{2P}{\pi}\frac{\cos^4\theta_1}{a} \quad . \quad . \quad (3)$$

on substituting $a = r_1\cos\theta_1$.

This then will be the approximate form of the loading on the boundary of the semi-infinite medium. As the medium and the foundation are not continuous at their common face, neither shear $\hat{x}y$ nor transverse normal stress $\hat{x}x$ will be transmitted by the foundation to the medium.

The problem thus reduces to determining the stress distribution in the medium subject to a boundary distribution of load as given by (3); the method of analysis employed is similar to that used by Filon.[4]

Consider an element δl on the boundary, distant l from the origin O (Fig. 1). Then the load on this element from (3) will obviously be

$$\hat{y}y\,\delta l = -\frac{2P}{\pi}\frac{a^3}{(a^2+l^2)^2}\delta l \quad . \quad (4)$$

since $\cos\theta_1 = \dfrac{a}{(a^2+l^2)^{\frac{1}{2}}}$.

Now this may be considered as a point load on the boundary of the elastic medium providing $\delta l \to 0$ and will obviously give rise to an analogous stress function to (1), of the nature

$$\delta\phi = \frac{\hat{y}y\,\delta l}{\pi} r\,\theta\sin\theta. \quad . \quad (5)$$

which, on substituting $r\sin\theta = x - l$ and $\theta = \tan^{-1}\dfrac{x-l}{y}$ and integrating, finally yields

$$\phi = \int_{-\alpha}^{+\alpha} -\frac{2P}{\pi^2}\frac{a^3}{(a^2+l^2)^2}(x-l)\tan^{-1}\frac{x-l}{y}\,\delta l. \quad . \quad . \quad . \quad (6)$$

Since we are concerned only with the stress distribution in the medium, the stresses

$$\hat{y}y = \frac{\partial^2\phi}{\partial x^2}; \quad \hat{x}x = \frac{\partial^2\phi}{\partial y^2}; \quad \hat{x}y = -\frac{\partial^2\phi}{\partial x\partial y},$$

may be conveniently determined by differentiating under the integral sign. Thus in avoiding the direct integration of the stress function and then having to differentiate again to determine the required stresses, the author has found that the solution of such stress problems is facilitated. This method may be extended to any type of stress problem of this nature.

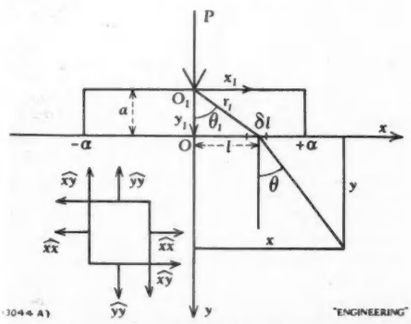


Fig. 1 Diagrams showing the directions of axes and stresses in the foundation block and in the semi-infinite medium on which it rests. The case is for a centrally-placed point load acting normal to the foundation.

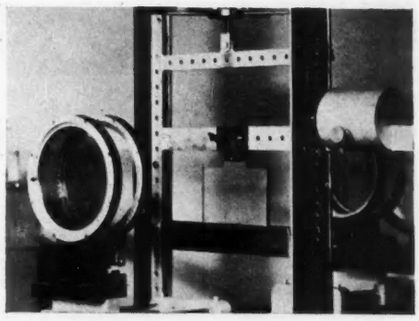


Fig. 2 Polariscope, showing model foundation.

Thus considering the normal vertical stress $\hat{y}y$ we have ultimately

$$\hat{y}y = \frac{\partial^2\phi}{\partial x^2} = \int_{-\alpha}^{+\alpha} -\frac{2Pa^3}{\pi^2}\times\frac{2y^3\,dl}{(a^2+l^2)^2\{(x-l)^2+y^2\}^2}. \quad (7)$$

This is most easily integrated by resolving into partial fractions and yields finally

$$\hat{y}y = -\frac{4Pa^3y^3}{\pi^2}\left[\begin{array}{l}\tan^{-1}\dfrac{l}{a}\left\{\dfrac{B}{a}+\dfrac{D}{2a^3}\right\}+\\ \tan^{-1}\dfrac{x-l}{y}\left\{\dfrac{Ex+F}{y}+\dfrac{Gx+H}{2y^3}\right\}+\\ \dfrac{1}{2(l^2+a^2)}\left\{\dfrac{Dl}{a^3}-C\right\}+\\ \dfrac{-1}{2(x-l)^2+y^2}\left\{G+\dfrac{(Gx+H)(x-l)}{y^2}\right\}+\\ \dfrac{E}{2}\log\left[\dfrac{(x-l)^2+y^2}{l^2+a^2}\right]\end{array}\right]_{-\alpha}^{+\alpha} \quad . \quad . \quad . \quad (8)$$

where B, C, D, E, F, G and H are defined by equation (10).

Now if α is allowed to tend to infinity, equation (8) reduces to

$$\hat{y}y = -\frac{4Pa^3y^3}{\pi}\left[\left(\frac{B}{a}+\frac{D}{2a^3}\right)+\left(\frac{Ex+F}{y}+\frac{Gx+H}{2y^3}\right)\right] \quad (9)$$

where

$$C = \frac{4xb}{\beta^2}; \quad D = \frac{(b^2-4a^2x^2)}{\beta^2};$$

$$G = \frac{4x(b-2x^2)}{\beta^2};$$

$$H = \left[\frac{(b-4x^2)^2-4x^2(b+a^2)}{\beta^2}\right];$$

$$E = \left[\frac{(C+G)(b+4x^2)-2x(4xC-D-H)}{\beta}\right];$$

$$B = \left[\frac{(C+G)-Eb}{2x}\right]; \quad F = -B-2xE; \quad . \quad . \quad .(10)$$

$$b = x^2+y^2-a^2 \quad \text{and}$$

$$\beta = (x^2+y^2-a^2)^2+4a^2x^2.$$

Now equation (9) is the unique solution for the normal stress $\hat{y}y$ in the case of boundary loading given by equation (3) and extending to infinity.

Now the boundary loading distribution $\dfrac{2Pa^3}{(a^2+l^2)^2}$ tends rapidly to zero as l becomes large. Thus the contribution to the total load on the boundary for large values of l will be negligible and thus in the case of a foundation of finite length the boundary loading will be approximately of the form given by equation (3). Thus the normal stress $\hat{y}y$ for large finite range of load will be approximately given by equation (9).

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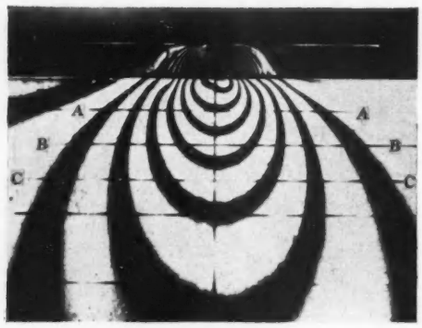

Fig. 3 Stress fringes for foundation 0·2 in. deep and with a length to depth ratio of 10.

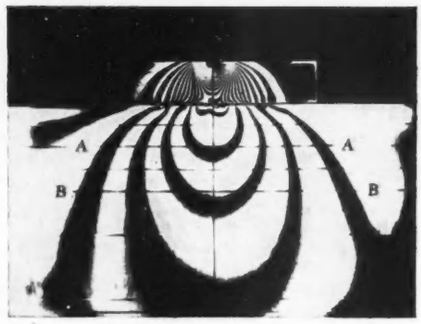

Fig. 4 Stress fringes for foundation 0·4 in. deep and with a length to depth ratio of 5.

In the same fashion $\hat{x}x$ and $\hat{x}y$ may be determined but for brevity will be omitted. On the section $y = 0$, the stresses $\hat{y}y$, $\hat{x}x$ and $\hat{x}\hat{y}$ may be shown to be[7]

$$\hat{y}y = -\frac{2P}{\pi}\frac{a^3}{(x^2+a^2)^2};$$

$$\hat{x}x = -\frac{2P}{\pi}\frac{a^3}{(x^2+a^2)^2};\ \hat{x}\hat{y} = 0. \quad (11)$$

Values for the normal stress $\hat{y}y$ were calculated for sections $y = 0$, a, $2a$ and $3a$ by determining the values of the constants C to F in equation (10) and substituting the relevant values in equation (9). These theoretical values were then compared with experimental values obtained photo-elastically.

PHOTO-ELASTIC INVESTIGATION

As the theoretical approach to the problem was two-dimensional, experimental verification could easily be obtained by photo-elastic methods. A plate of Catalin 800, 6 in. by 5 in., was used to represent the elastic medium and small rectangular sections of the same material placed on the boundary of the plate, then served as foundations. The model foundations were loaded centrally and viewed in the polariscope shown in Fig. 2; stress fringes and isoclinics were recorded.

As the depth of the foundation a was a fundamental constant in the formulæ (9) and (10), it was decided that the best experimental check would be to vary the depth of the foundations. Accordingly, three model foundations were tested of depths 0·2, 0·4 and 0·6 in. respectively, each being 2 in. in length. Thus while the foundation 0·2 in. deep had a length to depth ratio of 10 and thus conformed more to the assumption of infinite length of the theory, the other two ratios of 5 and 2·33 conformed more to those found in practice.

The shear difference method of analysis was used throughout as this offered the complete determination of the stresses $\hat{y}y$, $\hat{x}x$ and $\hat{x}\hat{y}$ along sections parallel to the boundary, i.e., for sections y = constant. This particular photo-elastic investigation was conducted at a much later date than previous work on this subject in order to investigate more thoroughly the validity of the previously derived equations for flexible foundations. The polariscope used was designed by the author and is housed in the Civil Engineering Department of the University of Glasgow.

The photographs of stress fringes in this section of the work were taken using circularly-polarised monochromatic light (sodium yellow). The stress fringes for the model foundation 0·2 in. deep are shown in Fig. 3. Photo-elastic analyses were conducted along the sections marked AA, BB and CC (i.e., for sections $y = a$, $y = 2a$ and $y = 3a$ respectively) on the photograph. A comparison between the theoretical and photo-elastic results is recorded in Table I. Again for brevity only the results for the normal stress $\hat{y}y$ are given for the three sections.

The comparison between the theoretical and photo-elastic results is good and it may be added that good comparison existed between similar results for $\hat{x}x$ and $\hat{x}y$. Because of the vagueness of the isoclinics in the immediate vicinity of the boundary, a satisfactory analysis along this section was unobtainable.

In the case of the foundation 0·4 in. deep, good agreement between theoretical and experimental values was again found; the stress fringes are shown in Fig. 4. The isoclinics were sufficiently clear on the boundary to allow analyses to be conducted along the foot of the foundation as well as along the boundary of the plate.

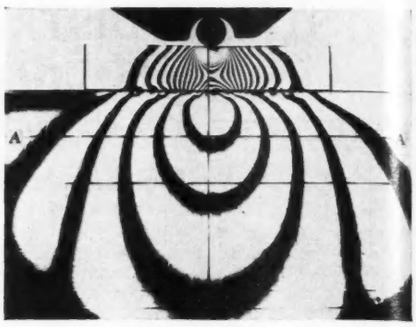

Fig. 7 Stress fringes for BT 61-893 foundation.

The results of these analyses are shown in Figs. 5 and 6. The curve for $\hat{y}y$ obtained photo-elastically for the base of the foundation is shown as the full line in Fig. 5, the broken line being the theoretical value. Graphical integration of the area under the photo-elastic curve for $\hat{y}y$ yielded a total normal load of 288 lb. as against the actual applied load of 257 lb. which was used in the determination of the theoretical curve; accordingly the experimental curve was high. Curves for $\hat{y}y$ along the boundary of the plate are shown in Fig. 6, the experimental being the full line and the theoretical the broken line. In this case the photo-elastic curve yielded a total normal load of 208 lb. and thus was of necessity low. Despite the difficulties of analyses in these boundary cases, reasonable agreement exists between the theoretical assumption of boundary loading, i.e.,

$$\hat{y}y = \frac{2P}{\pi}\frac{a^3}{(a^2+x^2)^2},$$

and experiment.

As the elastic moduli of the plate and the foundation were the same in the above cases, reasonable agreement between theory and experiment was to be expected. It was thus decided to observe the effect of varying the elastic moduli by choosing a harder material for the foundation; this obviously conformed more to the practical case. Thus, in the final experiment, the foundation was made of BT 61-893 with a Young's Modulus of approximately 6×10^6 lb. per square inch and the plate of Catalin with a modulus of approximately 3×10^6 lb. per square inch, the dimensions of the foundation being 0·4 in. by 2 in. The resulting stress fringes are shown in Fig. 7 and the results of an analysis along the section $y = 0{\cdot}4$ in. $= a$ are given in Table II.

Inspection of Table II shows that even in this extreme case agreement between theory and experiment for the normal stress distribution $\hat{y}y$ and the shear stress $\hat{x}\hat{y}$ was reasonable. It would thus seem from the photo-elastic analysis, that in the two-dimensional case, the boundary loading conditions (caused by the dispersion of stress due to the point load through the depth of the foundation) are as assumed in the theory and that the stress distribution in the medium

TABLE I.—Comparison Between Theoretical and Experimental Values for $\hat{y}y$ for Various Sections

Section	x	0	$0{\cdot}5a$	a	$1{\cdot}5a$	$2a$	$3a$	$4a$
$y = a$ ..	Experimental ..	6·75	6·10	4·10	1·95	1·20	0·00	0·00
	Theoretical ..	6·97	5·88	3·75	2·03	1·05	0·29	0·10
$y = 2a$ ..	Experimental ..	4·70	4·40	3·60	2·90	2·10	0·70	0·00
	Theoretical ..	4·56	4·25	3·43	2·55	1·70	0·71	0·31
$y = 3a$ ..	Experimental ..	3·70	—	3·10	—	2·10	1·30	0·60
	Theoretical ..	3·43	—	2·88	—	1·80	1·08	0·58

TABLE II.—Comparison of Theoretical and Experimental Results on Section $y = a$ for More Rigid Foundation

Stress	—	0	$0{\cdot}5a$	a	$1{\cdot}5a$	$2a$	$3a$
$\hat{y}y$ ..	Experimental ..	5·00	4·40	3·10	2·10	1·25	0·30
	Theoretical ..	5·50	4·64	2·97	1·60	0·83	0·23
$\hat{x}\hat{y}$ ..	Experimental ..	0·00	0·85	1·25	1·25	0·95	0·40
	Theoretical ..	0·00	1·16	1·48	1·20	0·83	0·35

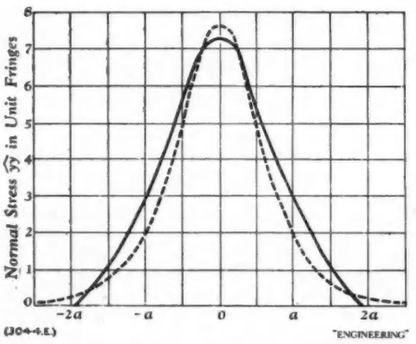

Fig. 5 Normal stress $\hat{y}y$ at base of foundation.

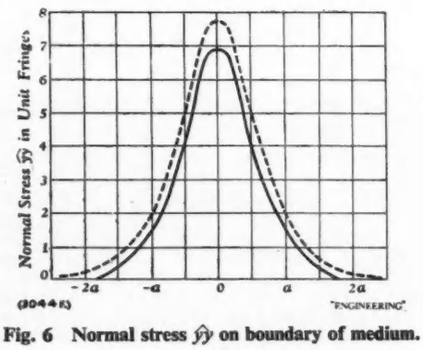

Fig. 6 Normal stress $\hat{y}y$ on boundary of medium.

under the foundation as given by the derived formulae is reasonably correct.

A SIMPLE THREE-DIMENSIONAL TECHNIQUE

The second part of this paper is devoted to a three-dimensional photo-elastic investigation of the stress distribution under a loaded foundation. In order to pursue this investigation a number of three-dimensional techniques were examined. Of the current techniques, stress "freezing" appeared to be the most convenient, but on further consideration the limitations of the method in this particular case became more apparent.

As a number of investigations were to be carried out, this technique would have required several blocks of photo-elastic material. Apart from this the necessary shape of the surface, so that it would deform to a plane under thermal-plastic flow, could not readily be determined. The following technique was adopted to overcome these difficulties.

A plate of BT 61-893 was cemented between two identical blocks of Perspex and load was applied to the surface of the block through a foundation. On viewing the block under polarised light, as Perspex is relatively stress-optically insensitive, retardation fringes appeared only in the more stress-optically sensitive BT 61-893 material. By displacing the foundation relatively to the plate various sections under the foundation could be examined. The advantages of this method were immediately obvious, only one block was required for all investigations, sectioning was unnecessary and the stress fringes and the isoclinics were immediately observable. The technique of the method and the experimental results will now be given.

Theoretical Consideration of the Composite Block.—Consider Fig. 8, in which AA are two identical blocks of a material which is stress-optically insensitive. Cemented between these blocks is a plate of highly sensitive material B. If the block is stressed by a load P applied through a foundation and is viewed under circularly-polarised monochromatic light the stress-optical law governing the interference phenomenon may be shown to be[7]

$$n \simeq \frac{1}{f_B}(p - q)_B \, t_B \quad . \quad . \quad (12)$$

where n is the number or order of the stress fringes, f_B is the material fringe value of the material B, p and q are the secondary principal stresses in the medium B, and t_B is its thickness.

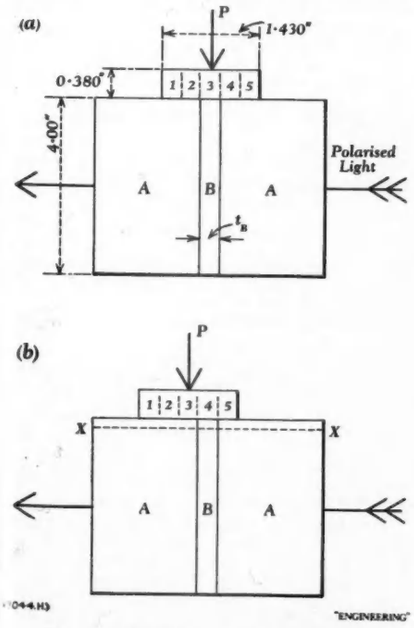

Fig. 8 Operation of composite block.

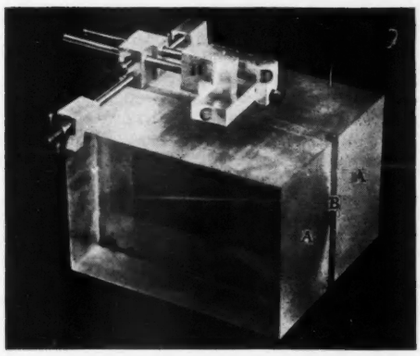

Fig. 9 Composite block with foundation and adjustable clamps.

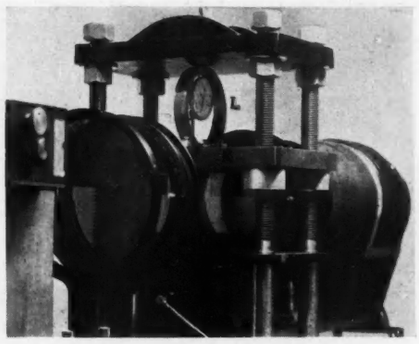

Fig. 10 Large transmission polariscope and loading ram.

The resulting stress fringe pattern appearing in B will be that due to the stress distribution in that particular section under the foundation and its interpretation will be governed by equation (12), provided that the following conditions are fulfilled: (*a*) the elastic moduli E and Poisson's ratio γ are the same for A and B in order that elastic continuity throughout the composite block shall be preserved; (*b*) the media A and B must be firmly cemented together; (*c*) the material fringe values f_A, f_B of A and B, respectively, shall be such that $f_A > f_B$, i.e., material A shall be relatively insensitive; (*d*) the foundation dimensions should be such that they localise the stress distribution in the block within the region of the plate B; (*e*) the plate B must be relatively thin so that the stress gradient across it is small.

Observe that the conditions (*a*) and (*c*) are dependent only on the physical properties of the two materials A and B, while if a suitable material A can be chosen such that it is totally stress-optically insensitive, i.e., f_A is very large, then condition (*d*) need no longer apply.

Construction of the Composite Block.—Before constructing such a block it was necessary to examine the elastic and stress-optical properties of various plastics. The only materials available at the time were Catalin, C.R.39, BT61-893 and Perspex, the moduli of which were determined by beam-deflection tests and the material fringe values f from tensile specimens, the results are recorded in Table III.

TABLE III.—*Properties of Plastics.*

Material	Material Fringe Value f, lb. per inch per fringe	Young's Modulus E, lb. per square inch
Catalin ..	27·1	251,600
CR39 ..	49·3	312,680
BT 61-893 ..	43·1	655,240
Perspex ..	765·0	439,340

Perspex being the only optically-insensitive material of the group was used for medium A in the composite block. BT61-893 was selected for medium B, thus condition (*c*), i.e., $f_A > f_B$ $765{\cdot}0 > 43{\cdot}1$ was clearly fulfilled, while condition (*a*), i.e., $E_A = E_B$; 439,340 as against 655,240 was approximately realised, Poisson's ratio for these materials being of the same order. The length of the foundation was five times the thickness of the plate B thus localising the stress distribution to the region of B, while the plate B was sufficiently thin, thus ensuring that the stress gradient was small.

The prepared sections of the block were cemented together using chloroform. The completed block together with the model foundation and positioning clamps is shown in Fig. 9. AA are two identical blocks of Perspex, while B is the plate of BT61-893 cemented between them. The Perspex model foundation C could be held in any desired position relative to the plate B by means of the clamp D, while load could be applied through the loading head H to any desired part of the foundation.

The polariscope and loading mechanism are shown in Fig. 10, I being a cylinder containing a ram operated hydraulically. This ram carried a plate J upon which the composite block was placed. A movable plate K rested on the loading head H and load was transmitted by the ram to H and recorded by means of the proving ring and gauge L.

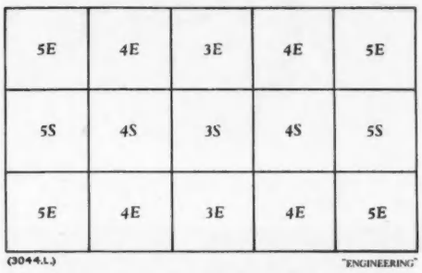

Fig. 11 Plan of foundation, showing sections to be loaded.

Method of Operation.—The composite block was placed between the polariser and analyser of the polariscope and was positioned so that the incident light was normal to the plane of the plate B in the block. The side of the foundation was marked off in five equal sections, as shown in Fig. 8, each being equal to the thickness of the section B.

Consider Fig. 8(*a*). The load P was placed over section 3 on the foundation and as this section was directly over the section B in the composite block, the stress fringes in B corresponded to the stress distribution under section 3 of the foundation. Stress fringes and isoclinics were then recorded for this position.

The foundation was now moved along until section 4 was directly over section B (see Fig. 8(*b*)). The position of the load P was still kept at section 3 on the foundation. The resulting stress fringes in the section B now corresponded to the stress distribution under section 4 of the foundation due to loading of the foundation at section 3. Stress fringes and isoclinics were again recorded for this section. The foundation was now moved until section 5 was over B (with the load P unaltered and at section 3 on the foundation) and the same procedure was carried out. Thus the stress distribution as determined from the stress fringes and isoclinics could be obtained for all sections under the foundation, the foundation being moved relative to B until the fringe order in the latter was no longer observable.

EXPERIMENTAL RESULTS

The foundation was divided in plan into 15 equal square sections which reduced by symmetry to six namely 3S, 4S, 5S, 3E, 4E and 5E, as shown in Fig. 11. This allowed six complete investigations to be carried out with the load P on each of the above positions in turn. The stress fringes for the case of the load P on position 3E on the foundation are shown for the sections 1, 2 and 3 in Figs. 12, 13 and 14. A plane parallel to the surface plane of the block was chosen, this is marked XX in Fig. 8 (*b*)

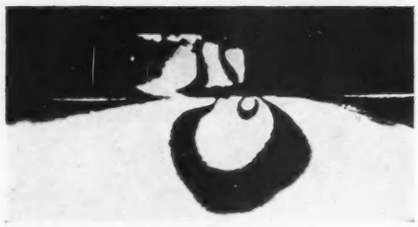

Fig. 12 Stress fringes for section 1.

Fig. 13 Stress fringes for section 2.

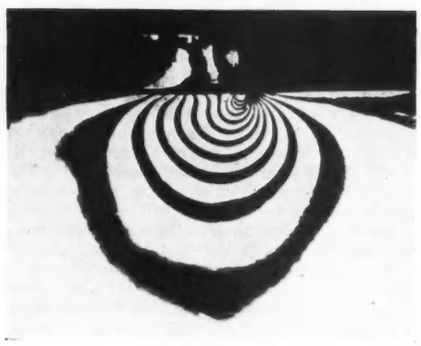

Fig. 14 Stress fringes for section 3.

and photo-elastic analyses along the sections of this plane intercepted by the sections 1 to 5 were conducted. Curves of the normal stress $\hat{yy}$ along the sections 1 to 3 are shown in Fig. 15. Now graphical integration of the areas under these curves will give the vertical load acting on the respective sections. The sum of such vertical loads should be equal to the known total applied load P; this provides an excellent check on the accuracy of the experimental data. In the above case the sum of the vertical loads acting on the sections 1 to 5 was found to be 720 lb. as against an applied load P of 780 lb., giving an error of some 7 per cent. Of the other five complete investigations this vertical load check yielded errors of −8·3, −2·5, −19·7, −7·5 and +3·5 per cent., indicating that the above three-dimensional technique was reasonably accurate.

The following conclusions may be drawn on examining Fig. 15. In all sections under the foundation, peak stress distribution occurs directly under the line of action of the load and the maximum of these peak values occurs at that section directly under the load. These peak values diminish as the sections recede from the directly loaded area of the foundation.

Conclusions.—It would seem that the three-dimensional technique is reasonably accurate, there being only one serious discrepancy in the vertical load check. Provided the recommendations laid down at the end of the section on the theory of the method are fulfilled, there seems to be no reason why this technique should not be extended to further types of three-dimensional investigations in engineering.

The technique, however, does demand that the cementing should be strong. It may be added that though the foregoing experiments were conducted from February to April, 1949, the block still remained intact and perfectly transparent four years later and its deliberate destruction required considerable force.

The advantages of this technique over stress "freezing" in this particular case will be briefly recalled. Only one block is required, sectioning is unnecessary (the inserted plate virtually replaces the "stress-frozen section") the stress fringes and isoclinics are immediately observable, the technique is conducted at room temperature, and no complicated machining of the surface is necessary for the deformed shape to be approximately a plane.

The author[8] has made different use of the relative optical sensitivity of two materials in examining the stress distribution in the traverses of shell roofs, by making one traverse of BT 61-893 and the other of Perspex. The direction of the polarised light was normal to the planes of the traverses, stress fringes were then observed only in the BT 61-893 traverse when the surface of the model shell was loaded.

Acknowledgment.—The main part of this work was carried out in the laboratories of King's College in the University of Durham and the co-operation of Professor W. Fisher Cassie and Professor E. L. J. Potts contributed much to its success.

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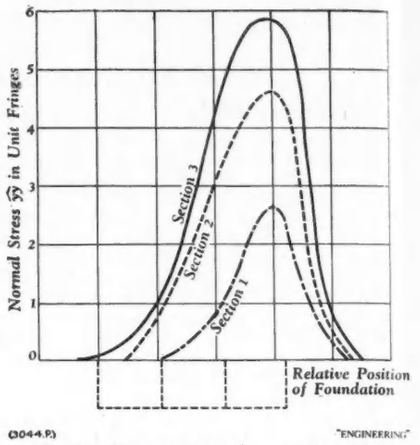

Fig. 15 Normal stress $\hat{yy}$ on sections XX.

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[5] Flamant, *Compt. rend.*, vol. 114, page 1465 (1892).
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TESTING FOR FLATNESS OR STRAIGHTNESS*

APPARATUS APPLIED TO PHOTOGRAPHIC PLATES

By J. C. Evans, B.SC., PH.D., *and I. G. Morgan*, B.A. (OXON)

Summary.—This article describes a simple pneumatic apparatus, working at a pressure of about ½ lb. per square inch, which enables the flatness of photographic plates to be checked rapidly prior to their use in the camera. The errors of flatness are shown directly by the levels of coloured-water columns in parallel manometer tubes; the magnification is 2,500 *and the linear range is* ± 15μ (± 0·0006 in.). *The apparatus essentially measures departures from a prescribed form and has therefore other applications.*

The apparatus described in this article was designed at the National Physical Laboratory to provide a method by which sensitive photographic plates can be tested for flatness without exposing them to light and without touching the emulsion. Since the apparatus is simple both in principle and in construction, and may readily be adapted for other applications, an account of it will probably be useful to other workers concerned with the measurement of flatness or, alternatively, of straightness.

Fig. 1 is a front view of the apparatus, with the case of the display unit removed. The photographic plates are placed in turn in the gauging fixture, which is to be seen on the left, and the errors of flatness are shown by the levels of coloured-water columns in the six manometer tubes. The magnification is 2,500 approximately and the scales are linear to within 1 per cent. over the range depicted, viz., from − 15μ to + 15μ (− 0·0006 to + 0·0006 in.). With the case of the display unit in position, the scales are visible through a window of suitable dimensions and a diagram immediately above the window shows the relation between the manometer tubes and the measuring points in the gauging fixture. The overall height of the display unit is about 60 cm. (24 in.) and the fixture is suitable for plates 54 mm. (2·1 in.) square.

The apparatus is an application of the pneumatic principle of gauging, a fuller description of which is given in previous papers†‡ so that only a brief reference to it will be necessary here. The principle is shown schematically in the upper part of Fig. 2. Air from a constant-pressure source is supplied first to an orifice O_1 and thence to an orifice O_2 through which it escapes to the atmosphere. P represents the constant pressure upstream of the first orifice and p that between the two orifices, both being referred to atmospheric pressure as datum. If C and M are the effective escapement areas of O_1 and O_2 respectively, the relationship between $\frac{p}{P}$ and $\frac{M}{C}$ is given by a characteristic curve of the general form shown in the lower part of Fig. 2. For values of $\frac{p}{P}$ between 0·6 and 0·8, the curve is linear to within 1 per cent. and for P of the order of 1 lb. per square inch may be represented by the equation

$$\frac{p}{P} = 1{\cdot}10 - 0{\cdot}60\,\frac{M}{C}$$

If then O_1 is fixed, so that both P and C are constant, while M is made linearly dependent on a dimensional quantity h, then within the range

* Communication from the National Physical Laboratory.

† "Continuous Pneumatic Gauging of Material in Thread or Wire Form." Evans, J. C., Graneek, M., and Loe, H. G. *Trans. Soc. Instrum. Tech.*, vol. 2, page 34 (1950).

‡ "A Sensitive Comparator for Measuring Variation in Diameter of Wires." Evans, J. C., Marriner, R. S., Morgan, I. G. ENGINEERING, vol. 173, page 529 (1952).

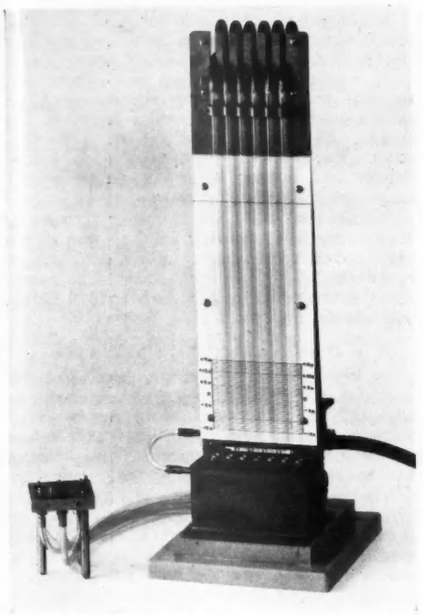


Fig. 1 Front view of apparatus with case removed. The gauging fixture, in which the plate is placed, is on the left, errors in flatness being indicated by the heights of the water columns in the manometer tubes.

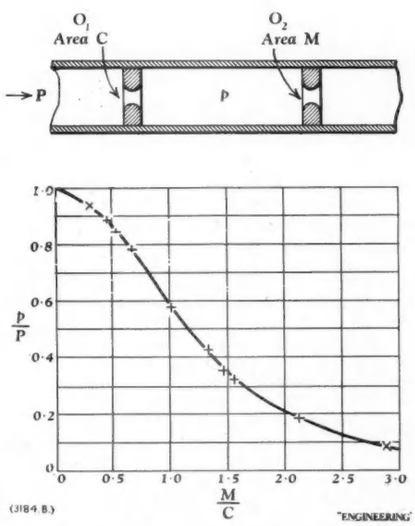


Fig. 2 Principle employed and characteristic curves.

stipulated, the pressure p will provide a proportional measure of h.

In the apparatus, O_2 takes the form of a jet with a circular orifice placed near a surface which impedes the flow of air from the jet. If d is the diameter of the jet and h the distance between jet and plate, the effective escapement area M at the jet is $k \pi d h$ where k is a numerical coefficient. M is therefore linearly related to h and hence, under the conditions stated above, p is also proportional to h. The sensitivity $\frac{dp}{dh}$ depends on the value of P and the mean clearance h. In the apparatus as designed, P is about 35 cm. (14 in.) of water and the mean value of h is 0·06 mm. (0·0025 in.).

The gauging fixture has six jets mounted in a steel plate which also carries three ball-ended supports on which the (photograpic plate) test-pieces are placed. Three short, vertical rods help to locate the test-piece laterally, and when correctly mounted the test-piece makes contact with the balls. The lower ends of the jets are threaded externally and fitted with lock nuts so that the position of each jet can be adjusted in relation to the plane defined by the three balls. This adjustment is readily made though the final setting can be more easily realised with the aid of a small bleeder valve connected in parallel with the jet, but more conveniently placed at the rear of the display unit, Fig. 3.

The pneumatic circuit employed, which is of course similar for each jet, may be traced in Fig. 3 with the aid of Fig. 4 which shows it in diagrammatic form. The mechanical regulating unit U, Fig. 4, maintains the constant pressure P at which air is supplied to the fixed orifice O_1, here a short length of glass capillary tubing, and thence to the measuring jet orifice O_2 and the parallel bleeder valve V. The pressure p is applied at the top of the manometer tube which dips into the air-tight reservoir R. The pressure P is also applied to the water surface in the reservoir so that the level of water in the manometer is the measure of $P - p$ while its change measures the change in p. It is necessary that each jet system should have the same sensitivity, which requires the jet orifices to be made as nearly identical as possible, and likewise for the control orifices. The use of glass capillary tubing provides an easy means of attaining six identical control orifices since they can be cut to the same length from a single "cane." The air escape from the bleeder valves is purposely kept very small so that variation from valve to valve as a result of slightly different settings will not influence the sensitivity. Another point to be noted is that the readings of the instrument are not independent of the volume of water in the reservoir and will therefore be influenced by losses due to evaporation. A change of 0·35 cm. (0·14 in.) in the water level in the reservoir will, however, result in only a 1 per cent. change in sensitivity so that an appreciable loss of water can be tolerated. A side window in the reservoir allows the water level to be noted and an adjustment can be made at any time by removing the filler-cap and adding more water.

The apparatus is initially set up with the aid of a master plate having negligible errors of flatness, such as an optical flat or a lapped steel plate. With this plate in position in the gauging fixture and the bleeder valves closed, the positions of the jets are adjusted in turn so as to bring the water level in each tube to the zero of the scale or just below, the final adjustment being then made by opening the corresponding bleeder valve. When the master plate is removed, the levels rise to within a few inches of the tops of the tubes; when the test-piece is then placed in the fixture the water columns are depressed and the errors of flatness shown directly by their new positions. At a point where the surface is convex downwards, the corresponding water level is below the zero line; when it is convex upwards it is above the zero line. Since the water levels are measures of pressure differences no error is introduced by drainage of the manometer tubes, so that the levels may be read immediately they are stable, that is, within one or two seconds of placing the test-piece in the fixture.

The engineer defines the error in flatness of a surface as being the separation of two parallel planes between which the surface wholly lies. Determination of the error in accordance with this definition calls for many measurements on the surface and a subsequent analysis of the results. The apparatus which has been described is not intended to serve this end: its purpose is to enable a rapid assessment to be made as to whether or not the error of flatness exceeds a prescribed amount. The number of measuring points (jets) used will depend on the application; the prototype has six jets but this number could be increased if required.

The principle used in this apparatus can readily be applied to the measurement of straightness by setting all the jets in a single line, and

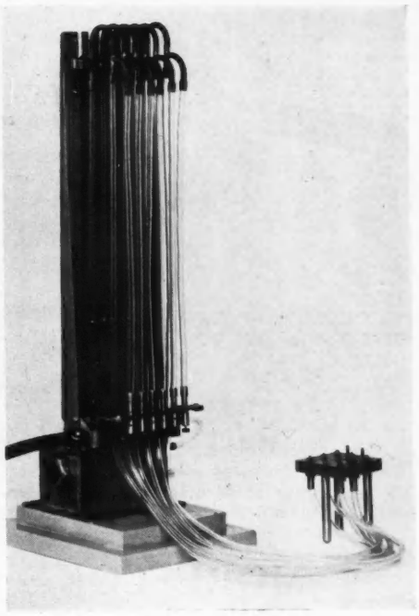


Fig. 3 Rear view of display unit.

equipment of this kind is now being developed for measuring the straightness of cylindrical bars. In this case, a higher sensitivity is needed so that departures from straightness may be measured to about 0·1μ (0·000,005 in.). A tenfold increase in sensitivity with the same mean jet clearance can be obtained by a tenfold increase in the applied pressure P, and the same display unit may be used provided the air pressure in the reservoir is modified suitably. This can be done by applying the pressure P to an auxiliary pair of orifices and applying the pressure between them to the water surface in the reservoir. The second orifice, which may again be a jet blowing on a plate, is adjusted (by positioning the plate) so as to give the differential pressure necessary to bring the water levels into the range of the manometer tubes. A stop-cock fitted in the supply is now essential to enable the supply to be cut off before removing a test-piece from the gauging fixture and so to prevent water from being blown from the manometer tubes into the other parts of the apparatus. It will be appreciated that the apparatus essentially measures departures from a prescribed form. With a suitably designed gauging fixture and a standard of known error, verifications of form can be very simply and conveniently made.

The authors desire to acknowledge the assistance rendered by Mr. E. P. Goymour who constructed the apparatus. The work described above has been carried out as part of the research programme of the National Physical Laboratory, and this article is published by permission of the Director of the Laboratory.

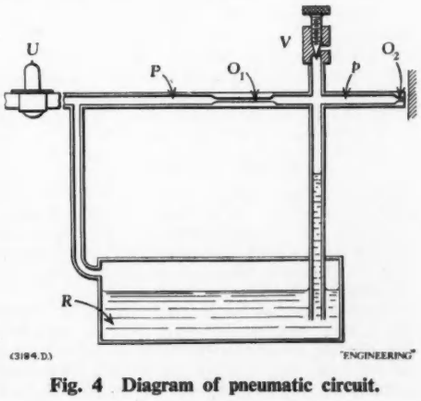
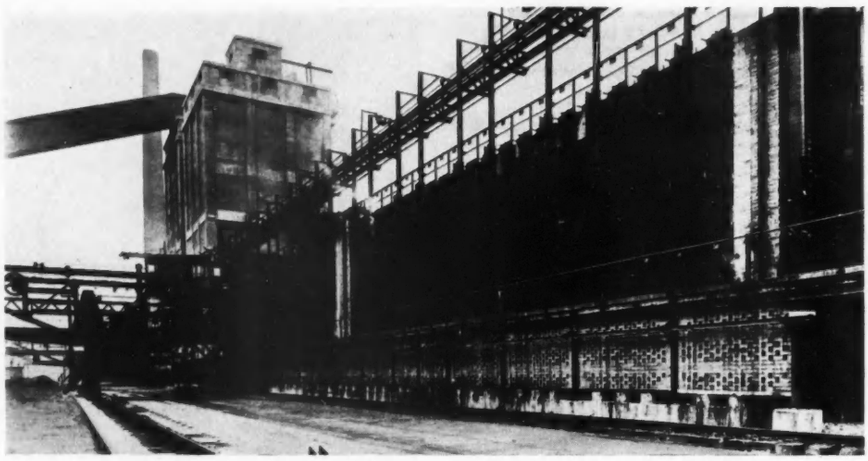


Fig. 4 Diagram of pneumatic circuit.



The new battery of 44 ovens from the pusher side. It is divided into two groups, of 21 and 23 ovens, to facilitate future rebuilding.

MORE COKE FOR PIG IRON

EXTENSIONS TO THE STANTON IRONWORKS PLANT

The Stanton Ironworks Company, Limited, operate five blast furnaces in two plants, of three and two furnaces, and extensive foundries at Stanton-by-Dale, near Nottingham. Prior to the outbreak of the last war all the coke required for the furnaces was purchased in the open market, but in 1939 the construction of a coke-oven battery was commenced at Hallam Fields, near to the furnaces. Commissioned in 1941, the battery consists of 41 ovens of the Woodall-Duckham Becker combination regenerative type, designed to carbonise 860 tons of coal a day. The coke ovens were provided with all the necessary ancillaries, including plant for coal-handling, blending and crushing, by-product recovery, and steam-raising. These ovens produced about half the coke required at the furnaces. About 40 per cent. of the coke-oven gas made was used for under-firing the ovens, the remainder was sold to the neighbouring towns of Nottingham, Derby and Long Eaton. The plant as originally built was designed for doubling in size at a later date, and in 1951 it was decided to carry out this extension. At the same time blast-furnace gas-cleaning equipment was installed at the company's two blast-furnace plants. Clean blast-furnace gas is now used for firing both the old and the new coke-oven batteries, and the entire output of coke-oven gas is sold to the East Midlands Gas Board. The coal-handling plant has been modified, and additional units have been added to serve the two coke-oven plants, which operate as a complete unit, carbonising 1,950 tons of coal a day, and producing, in the same period, 1,450 tons of coke, 14,500 gallons of crude tar, 5,000 gallons of refined benzole products, 22 tons of sulphate of ammonia, and 24 million cub. ft. of gas. Firing consumes 50 million cub. ft. of blast-furnace gas. The new plant was brought into commission in April, 1955, and the official inauguration was performed by the Minister of Fuel and Power, the Rt. Hon. Mr. Geoffrey Lloyd, M.P., on September 22, 1955.

COAL HANDLING

The coal used in the ovens is brought from the Nottinghamshire, Derbyshire, Yorkshire, Durham, and Welsh coalfields, and is all rail-borne, the site being served by sidings from both the London Midland and Eastern Regions of British Railways.

Coal wagons arrive at the north side of the plant, and are dealt with by two Mitchell Engineering side-discharge tipplers which incorporate weighing equipment. Both tipplers are capable of handling wagons of up to 24½ tons capacity and can deal with 150 tons of coal per hour. Coal from the tippler hoppers is elevated by a 30 in. inclined conveyor to the top of the blending bunkers, or alternatively, it can pass by a short conveyor system to a British Jeffery-Diamond hammer-mill primary crusher, which reduces any run-of-mine or graded coal so that 95 per cent. passes through ½ in. square mesh. Coal which passes through this crusher returns to the main 30 in. belt for elevating to the blending bunkers, of which there are five, each with a capacity of 200 tons. A reversing shuttle-conveyor delivers the coal to any one of the bunkers as required. Magnetic separators are suspended over the belts leading from both tipplers to the main elevating belt, to remove tramp iron.

Coal is withdrawn from the blending bunkers over Richard Simon constant-weight feeders of the belt-weighing type, one for each bunker, and discharged to a belt conveyor feeding a secondary crusher. This is a Mansfield hammer mill, which reduces the coal so that 80 per cent. passes through ⅛ in. square mesh. A duplicate hammer mill is provided as a stand-by. Fine adjustment is provided on the Simon feeders, and any required blend of the coals from the bunkers can be maintained automatically. An oil-feed line, controlled by a valve which closes automatically when the belt stops, feeds oil at a rate of ½ gallon per ton of coal to the secondary crusher feed belt.

Provision has been made for stocking up to 30,000 tons of coal on the ground to the east of the coke ovens. Rail wagons are unloaded by a Strachan and Henshaw side-tippler, and the coal transferred to the site by means of conveyors discharging on to a heap on the ground. Distribution over the site is by bulldozer. Reclaiming is also by bulldozer, into an underground hopper feeding a wagon-loading bunker by means of a conveyor.

Blended coal from the secondary crusher is elevated by belt conveyor to the tops of two reinforced-concrete service bunkers, each capable of holding 1,700 tons. It is distributed evenly over the whole area of each bunker by a radial-type shuttle-conveyor.

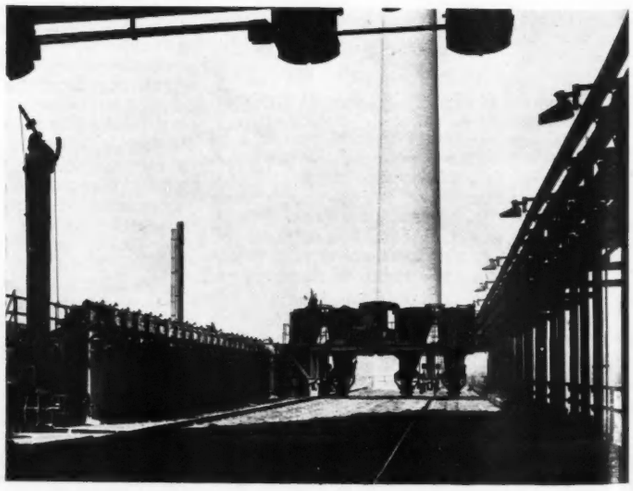
THE NEW COKE OVENS

The new coke-oven battery is largely a duplicate of the older one, except that it contains 44 ovens instead of 41 ; it also incorporates several minor modifications in design to take advantage of the most modern practice. The principal modifications are hammer-head design of oven-wall bricks, and the use of special fireclay blocks for the regenerator filling. The ovens are 40 ft. 8 in. long between doors, 12 ft. 6 in. high, and 16 in. mean width, with a taper of 2 in. Each will hold 14·5 tons of coal with a moisture content of 9 per cent. The ovens in the new battery are separated into two groups, of 21 and 23, by means of a division wall to facilitate future rebuilding. The oven doors are of the Wolff " hammer " seal type, clamped pneumatically.

The two batteries, old and new, are independently controlled by reversing machines, at the coal-bunker ends, which are coupled to the various gas and air supply valves of the respective batteries. The machines operate at intervals of 30 minutes, the reversal times being staggered. A stand-by steam reversing unit is provided, together with push-button control of the machines for emergency use. Automatic alarms operate in case of a reversal failure, or if the pressure in the blast-furnace gas supply main should fall below a pre-determined figure.

The ovens are charged from the overhead service bunkers by means of two Wellman Smith Owen portal-type charging cars which traverse the full length of the top of both batteries. Weighbridges are built into the car tracks under the service bunkers. Each car has four hoppers of 14½ tons total capacity, and is propelled by a 30 h.p. electric motor. Electrically-operated vibrators are fitted to each hopper, and each one has also an adjustable measuring device. The drop-sleeves and discharge gates are operated individually from the car driver's cabin.

When carbonisation is complete the hot coke is discharged from the oven by one of two Wellman Smith Owen combination coke pushers. Each of these two machines will travel the whole length of the two batteries, and will remove and replace the doors on the pusher side, level the



There are two charging cars, both of which will travel the full length of the two batteries. The new battery is illustrated here.

coal charge, and push out the hot coke. They are electrically propelled, with a 50 h.p. motor for travelling, one of 70 h.p. for pushing, and one of 30 h.p. for levelling. The door extractor is powered by a 5 h.p. motor, and a further motor, of 3 h.p., is used for door-latch operation. Each machine incorporates an air compressor which supplies air to the top of the pusher head for the removal of roof carbon.

Hot coke is received by a coke-quenching car hauled by an electric locomotive driven by an 80 h.p. motor; both car and locomotive were built by Robert Stephenson and Hawthorns, Limited. An air compressor, driven by a 10 h.p. motor, is incorporated in the locomotive for operating the pneumatic doors on the coke car. A Diesel locomotive is available as a stand-by. A safety series of interlocking electrical circuits, of Stanton design, prevents the coke from being pushed unless the coke guide on the discharge side is in position and correctly aligned. The doors on the coke side are handled by two Wellman Smith Owen door machines.

Quenching of the hot coke in the car is by a controlled quantity of water in a brick tower at the west end of the plant, the coke is then discharged from the car to an inclined wharf ready for transfer to the screening plant. Breeze passing into the water sump is removed by a grab and hoist and delivered to rail wagons.

Coke is taken from the wharf to the screening plant by belt conveyor. It passes first over a Fraser and Chalmers single-deck Gyrex screen to take out the blast furnace coke (over 1¼ in.), which is loaded by boom conveyor to rail wagons. Undersize from the primary screen passes to a secondary Gyrex screen, where a second separation, at ¾ in., is made. Oversize is sold as domestic coke nuts, and the breeze is used on the coke oven boilers, or sold.

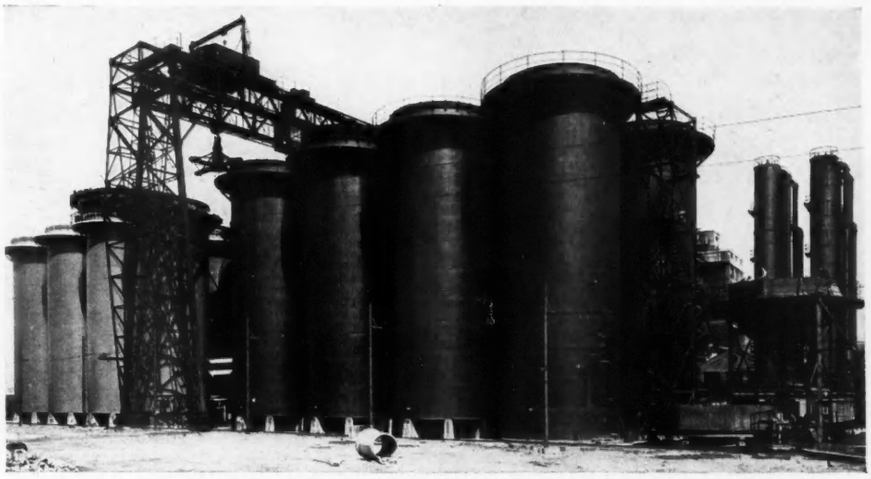
GAS COLLECTION AND DISPOSAL

The gas streams from the old and new coke-oven batteries are independent up to the benzole-scrubber outlets. Crude gas passes through ascension pipes into collecting mains running the full length of the old battery and divided into two sections on the new ovens. An Askania regulator maintains the gas at a constant pressure in the collecting mains. An offtake main leads to the primary coolers. Downcomers conduct the condensed tar and ammonia liquor into the liquor-flushing and separating tank, which is of the mechanically-operated scraper type. Here the tar is separated from the ammonia liquor by decantation. Part of the liquor is pumped into the collecting main through sprays to cool the hot crude gas; the remainder is pumped to storage and thence to stills for ammonia recovery.

The gas from each battery is drawn through the offtake mains to two primary coolers of the vertical water-tube type, operating in parallel, where it is cooled to 30 deg. C. A fifth cooler can be coupled into either circuit. From each set of primary coolers the gas is delivered by British Thomson-Houston steam turbine-driven exhausters to electrostatic de-tarrers. Three exhausters are installed, one for each gas stream and one as a stand-by. Each has a maximum capacity of 830,000 cub. ft. of gas per hour at 60 deg. F. and 30 in. mercury, against a pressure of 3¼ lb. per square inch. Askania governors control each exhauster through a servo-motor and steam throttle-valve.

The four de-tarrers are of the Whessoe Woodall-Duckham vertical-tube, suspended-wire-electrode type. One pair in parallel is in circuit on each gas stream. Three combined transformer-rectifier sets are installed, each rectifier having an output of 90 mA at 33,000 volts.

After leaving the de-tarrers the gas passes through a reheater, where it is heated to about 65 deg. C. It is then joined by the ammonia vapour recovered in the ammonia stills from the liquor from the gas-collecting system. Treatment with sulphuric acid in saturators follows, for the production of sulphate of ammonia. There are three saturators, one for each gas stream, and one as a stand-by; each one is equipped with a Monel metal draining table. Drained crystals are fed to three Watson-Laidlaw motor-driven centrifugal driers, each with a capacity of 600 lb. of sulphate. From the centrifugal driers the salt passes over belt conveyors to a Dunford and Elliott rotary louvre-type hot-air drier, which has a capacity of 32 tons per day. The dried salt is elevated to a bagging hopper which feeds an automatic bag-filling and weighing machine.



Two sets of tower purifiers ensure the complete removal of hydrogen sulphide from the gas, the entire output of which is sold to the East Midlands Gas Board.

Gas leaves the acid separators at a temperature of about 55 deg. C., and passes through final coolers before entering the benzole scrubbers. There are two final coolers, one for each gas stream. They are of the vertical cylindrical type, 8 ft. in diameter and 80 ft. high. In order to avoid atmospheric pollution by hydrogen sulphide, wash-oil is used in a closed circuit, and the oil from each cooler is itself cooled in two sets of oil-to-water heat exchangers. Each stream of gas from the final coolers then passes through two benzole scrubbers in series. These are 9 ft. in diameter and 96 ft. high, and equipped with a receiving tank in the base for the benzolised oil, which is pumped to the crude benzole recovery plant.

GAS PURIFICATION AND BENZOLE RECOVERY

From the outlets of the benzole scrubbers the gas enters a common main to the purifiers, which are of the Holmes tower type. They are arranged in two sets, each set comprising six working towers, one sealed stocking tower and one stocking frame; the capacity of each set is 12 million cub. ft. per day. The towers are 65 ft. high and 27 ft. 3 in. in diameter, with 15 oxide baskets in each one. A 50 ton Goliath crane is used for basket-changing and servicing.

To reduce the calorific value of the coke-oven gas to the figure specified by the Gas Board, a rapid-mixing chamber is provided for dilution with blast-furnace gas. An Electroflo constant-ratio regulator controls the dilution; it is re-set automatically as required by the deflection of the pen-arm of a Sigma recording calorimeter. After dilution, the gas passes to a Dempster-M.A.N. waterless gasholder, 140 ft. high, and with a capacity of 500,000 cub. ft.

From this holder gas is drawn by a booster plant and delivered into the Gas Board's mains. Three Connersville meters are installed on the inlet side of the boosters for measuring the volume of gas delivered. There are two Waller two-crank vertical enclosed compressors, working against a pressure of 25 lb. per sq. in., and each capable of delivering 10 million cub. ft. of gas per day. They are driven by Laurence Scott motors of 730 h.p. operating at 3,300 volts. Two further Waller compressors are also installed, of similar design, but with a capacity of 8 million cub. ft. per day each, and driven by Ashworth and Parker 540 h.p. compound steam engines. The gas leaving the boosters passes through three after-coolers in series and a tower in which ascending gas is washed by a descending solution of calcium chloride. The solution is re-concentrated over steam-heated evaporators and re-cooled for use again.

Wash-oil from the benzole scrubbers, enriched with benzole, passes through two vertical-tube heat exchangers, where it is heated to about 70 deg. C. It is then further heated to about 130 deg. C. by means of closed steam, and enters the wash-oil stills, of which there are two. Each has a series of trays where the benzole is removed from the descending wash-oil by contact with open steam admitted at the bottom of the still. The hot stripped oil is pumped through coolers and re-circulated to the scrubbers. The wash-oil in circulation is kept in good condition by bleeding-off a quantity continuously and passing it through two Clayton oil regeneration plants, each of which has a capacity of 70 gallons per hour. In these the clean, lower-boiling fraction is distilled off, condensed, and returned to the wash-oil circulation system. The residue and sludge are used for oiling the coal.

Crude benzole vapour from the wash-oil stills is condensed in vapour-oil heat exchangers and coolers, and it then passes to a separator where the crude benzole is removed from the water and run to a storage tank. From this point the benzole is pumped to Barbet stills, where carbon disulphide is removed by fractionation. Hot CS_2-free benzole is delivered from the stills into a continuous "once-running" column, where the oily constituents are removed by fractionation. Vapours from the column are condensed, and the "once-run" benzole is stored for further treatment. The residue is pumped to open pans where, on cooling, naphthalene crystallises out. The oil is separated by centrifuge and returned to the wash-oil circulation system and the naphthalene bagged for dispatch. A batch "once-running" still of 5,000 gallons capacity is provided as a stand-by.

The "once-run" benzole is pumped to two benzole agitators, where strong sulphuric acid is added to polymerise and remove gum-forming hydrocarbons and other impurities. Further washing with water and caustic soda follows, and the benzole then passes to the final rectification stills for steam distillation. The final products are motor benzole, pure benzole, nitration toluole, and zylole.

About half the steam required on the plant is generated in two Babcock and Wilcox boilers with chain-grate stokers burning coke breeze. One boiler is normally in use. The remaining steam requirements are met by a supply of pass-out steam from the blast-furnace plant. All exhaust steam is condensed, and the condensate is pumped back to the blast furnace plant boilers via an electric de-oiling unit.

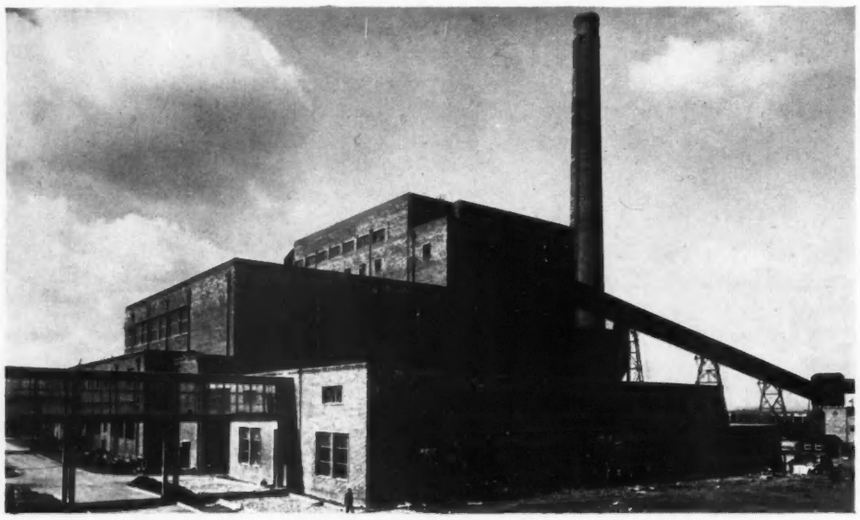


Fig. 1 Exterior of the 120-MW power station at Bold, St. Helens.

120-MW BOLD "A" POWER STATION

NOVEL FUEL-SUPPLY AND COOLING-WATER ARRANGEMENTS

The Bold "A" power station in the North West Merseyside and North Wales Division of the Central Electricity Authority, which was formally opened by Mr. J. Eccles, Deputy Chairman (Operations) on Friday, September 30, is situated about three miles from St. Helens and is interesting from the fact that it is supplied with coal directly from an adjacent colliery and that, as is becoming common, sewage effluent is used for cooling. The first of its four 30 MW sets came into operation in December, 1953, and the second in November, 1954. The third and fourth sets are planned for completion in 1957. A second station with an ultimate capacity of 180 MW is to be built on an adjacent site and will be known as Bold "B."

The buildings, which are illustrated in Fig. 1, are, with the exception of the chimneys and some of the coal conveyor trestles, supported on boulder clay, which lies only 1 ft. below the surface. The boiler house, turbine house, workshop and circulating-water pump house are of steel-frame construction with brick cladding and aluminium roof decking. The 33-kV switch house and administration offices are of concrete-encased steel framing with brick cladding and hollow pre-cast concrete roof beams finished with felt. The main building contractors were John Laing and Son, Limited, Bunns-lane, London, N.W.7, the steelwork being supplied by Dorman, Long and Company, Limited, Middlesbrough.

COAL-SUPPLY SYSTEM

It is anticipated that it will be possible to obtain about 550,000 tons of washed slack of 1 in. or smaller size for use at the station from the adjacent colliery and that this will be sufficient to raise steam for the 300 MW of generating plant which will eventually be installed on the site. On leaving the colliery the coal, which is supplied on a two-shift basis, passes through a batch weigher and automatic sampler which has been provided by the National Coal Board for costing purposes. It is then discharged on to an electrically-driven belt conveyor, which was constructed by Spencer (Melksham) Limited, Melksham, and has a capacity of 200 tons per hour at a speed of 300 ft. per min. This conveyor terminates at a main junction tower whence the coal can be delivered by a radial conveyor to a store with a capacity of 117,000 tons at a depth of 15 ft. It can be reclaimed by mobile handling plant consisting of two Fowler 95-h.p. Diesel crawler tractors which are fitted with hydraulically-operated angle-dozers. The capacity of this plant, which was supplied by Thos. W. Ward, Limited, Sheffield, is 100 tons per hour. The main junction tower can also be supplied with rail-borne coal at the rate of 200 tons per hour through a side-discharge tippler and conveyor. A view of the conveyor gantries and junction tower is given in Fig. 2.

From the main junction tower the coal is carried by a belt-conveyor system with a capacity of 200 tons per hour to the boiler-house bunkers through a magnetic separator, screens and crushers and an automatic sampler. An "Adequate" belt weigher is incorporated in the inclined conveyor to the bunkers. This system, which has a capacity of 200 tons per hour and runs at 310 ft. per min., was constructed by Naylor Bros., Limited, Golborne, Lancashire, and has been designed so that conveyors can be added to deal with the coal for the "B" station.

STEAM-RAISING PLANT

From the bunkers the coal passes through chutes to mill feeders of the rotating-table type of which there are three per boiler, the capacity of each being 28,000 lb. per hour. It is then delivered to Lopulco pulverisers constructed by International Combustion, Limited, Woburn-place, London, W.C.1, of which there are also three per boiler.

After pulverisation the fuel is transmitted to 12 Lopulco burners, which are situated at each corner of the boiler furnace in banks of three. The flames from these burners are directed tangentially to a circle with its centre at the intersection of the diagonals. Oil burners of the Wallsend Slipway type are installed at each corner of the combustion chamber for lighting-up purposes and are ignited by low-voltage electric pokers, the oil having previously been heated by electric immersion heaters.

The two boilers at present installed were constructed by Yarrow and Company, Limited, Scotstoun, Glasgow, W.4, and are of that firm's twin-drum type. Each is capable of supplying 300,000 lb. of steam per hour at a pressure of 625 lb. per square inch and a temperature of 865 deg. F. A water-cooled furnace is provided for each boiler, the combustion chamber volume being 21,900 cub. ft. The superheater, the total heating surface of which is 9,420 sq. ft., is of the "Melesco" self-draining type with one steam pass, while the economiser is of Green's double-flow construction and has a heating surface of 21,300 sq. ft. The tubular air heater has a heating surface of 79,600 sq. ft.

Air for combustion in each boiler is obtained from two forced-draught fans with an individual output of 57,000 cub. ft. per minute and the gases are withdrawn from the furnace by two induced-draught fans with an output of 79,000 cub. ft. per minute. All these fans were manufactured by Davidson and Company, Limited, Belfast. Dust is extracted by two two-stage Lodge-Cottrell electrostatic precipitators, which are arranged in parallel.

Fully automatic control of the boiler output is maintained by the adjustment of the combustion air supply in relation to the steam output in conjunction with the supply of coal to the pulverisers. The equipment installed for this purpose was provided by Electroflo Meters Company, Limited, Park Royal, London, N.W.10.

ASH AND DUST HANDLING

The ash-handling plant is designed to deal with the ash and dust accumulated during the steaming of four boilers at maximum continuous rating for a maximum period of 16 hours and removal can be completed in seven hours. The plant, was manufactured by B.V.C. Industrial Constructions, Limited, Grosvenor-gardens, London, S.W.1.

TURBINES AND FEED-HEATING SYSTEM

The generating plant in the first half of the station consists of two 30-MW sets of Metropolitan-Vickers manufacture, a view of one of which is given in Fig. 3. The turbines are of the two-cylinder impulse type and are normally

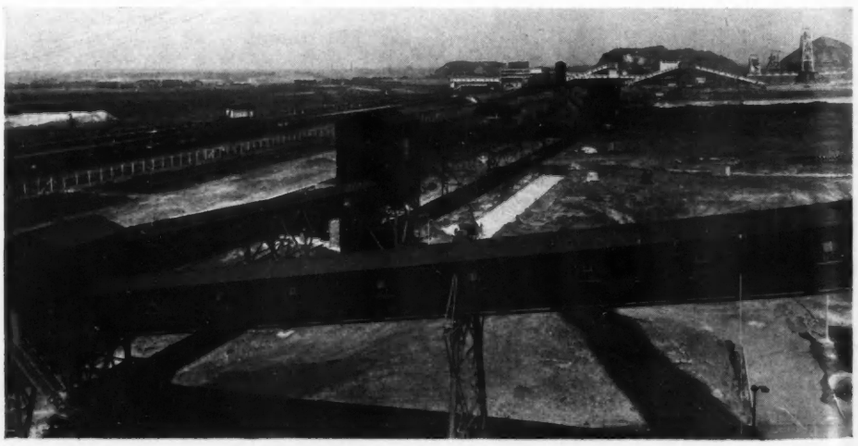


Fig. 2 The conveyor system by which coal is supplied direct from an adjacent colliery.

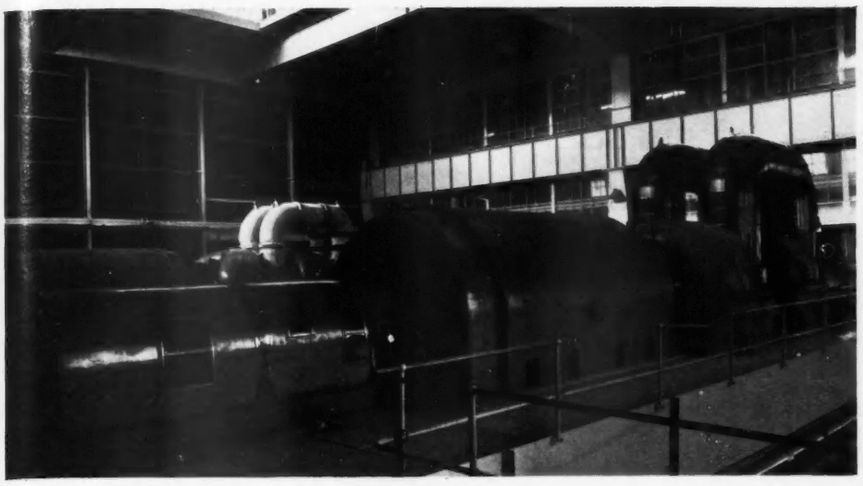


Fig. 3 One of the 30-MW turbo-alternators now operating at Bold.

supplied with steam on the unit system, although a " hospital " connection has been provided for use in emergency. They exhaust into twin three-flow condensers, manufactured by Vickers-Armstrongs, Limited, Broadway, London, S.W.1. which have a cooling surface of 27,000 sq. ft. The condensate is passed back to the boilers through a feed-heating system consisting of two main three-stage steam-operated air ejectors and a quick-start ejector; two low-pressure feed heaters; three motor-driven and two steam-driven feed pumps; and two high-pressure heaters, the final temperature at full load being 345 deg. F. Make-up is from two sets of Aiton's triple-effect live-steam evaporators, each with an output of 20,000 lb. of distilled water per hour. Shunt type de-aerators of the direct-contact type are also installed to ensure that a supply of air-freed water is always available. The main contractors for the feed-heating plant were also Vickers-Armstrongs Limited, the feed pumps being manufactured by the Harland Engineering Company, Limited, Alloa, and the steam turbines driving them by Mirrlees, Watson and Company, Limited, Scotland-street, Glasgow, C.5.

COOLING TOWERS

One cooling tower, with a capacity of 2·8 million gallons per hour and capable of reducing the temperature of the water from 82·5 deg. to 70 deg. F. with an air temperature of 57 deg. F. and a humidity of 70 per cent., is to be provided for each pair of generating sets by Film Cooling Towers (1925), Limited, 14 Lincoln's Inn Fields, London, W.C.2.

On completion of the new St. Helens sewage works, some two miles from the station, effluent will be drawn from twin reinforced-concrete balancing tanks by six vertical-spindle pumps, each with a capacity of 500 gallons per minute, which were manufactured by W. H. Allen Sons and Company, Limited, and are driven by 415-volt British Thomson-Houston motors. These pumps will force the effluent through two 15-in. bore asbestos-cement pipes to the cooling tower ponds.

As regards the electrical equipment of the station, the Metropolitan-Vickers alternators which generate three-phase current at 11·8 kV when running at 3,000 r.p.m., are solidly connected through 36-MVA, 11·8/35·4 kV transformers, manufactured by Brush Electrical Engineering Company, Limited, Loughborough, to the 33 kV system. These transformers are of forced oil/air blast type, there being two 50-per cent coolers on each unit. Each transformer is provided with " on-load " tap-changing equipment and inhibitors will be employed in some to investigate their effect on the life of the oil.

The main 33-kV switchgear, which was manufactured by A. Reyrolle and Company, Limited, Hebburn, Co. Durham, is illustrated in Fig. 4. It is of that firm's bulk oil type and has a rupuring capacity of 750 MVA. Accommodaton is provided for equipment to control four generators, two station transformers and eleven feeders, as well as busbar coupler and busbar section units.

The motors driving the essential auxiliary plant are supplied directly from the associated alternator through 11/3·3-kV Brush transformers, while those driving the " non-essential " auxiliaries and providing other supplies in the station are fed from the bus-bars through 6-MVA, 33/3·3-kV units. The 3·3-kV and lower voltage switchgear is of the air-break and switch-fuse types and was manufactured by the English Electric Company Limited, Kingsway, London, W.C.2.

The consulting engineers in the initial stages of the Bold project were Messrs. Kennedy and Donkin, but when, at the end of 1949, it was decided to make it, wherever possible, a duplicate of the Roosecote station their place was taken by Messrs. Merz and McLellan, with whom Messrs. James Williamson and Partners were associated for the civil-engineering work.

The Controller of the North West, Merseyside and North Wales Division of the Central Electricity Authority is Mr. A. R. Cooper, while the chief generation engineer (construction) is Mr. C. R. Watson Smythe and the station superintendent, Mr. R. Thistleton.

Fig. 4 The 750-MVA 33-kV switchgear.

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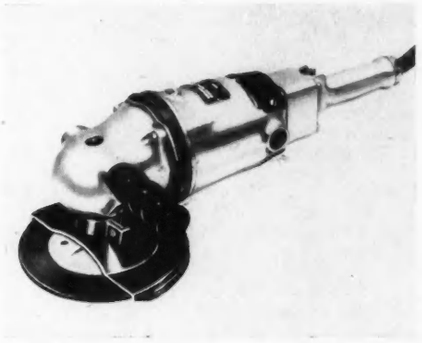
HEAVY-DUTY PORTABLE SANDER-GRINDER

A portable electric tool weighing 14 lb. has recently been introduced by Black and Decker, Limited, Harmondsworth, Middlesex. It is designed to replace the firm's existing 7 in. heavy-duty sander-grinder and is stated to be lighter and 90 per cent. more powerful than its predecessor. It is available in three models with spindle speeds of 4,200, 5,200 and 6,000 r.p.m., respectively, each of which is intended for a specific range of work. For instance, the two lower speed models are suitable for use with planer heads for wood, sander grinding wheels, wire cup brushes and sanding discs. The highest speed model is primarily intended for use with nylon-bonded depressed-centre cutting-off wheels, as shown in the illustration.

The new tool requires an electrical input of 1,060 watts at 115, 125, 220 or 240 volts. A replaceable steel ring is provided to protect the main housing from wear and damage and the brushgear is sealed against the entrance of dust. A removable steel plate gives access to the brushes and commutator; and also prevents wear at the rear of the main housing.



7-in. 6,000-r.p.m. heavy-duty sander-grinder fitted with a nylon-bonded cutting-off wheel.

The switch is enclosed in a compartment to protect it from abrasive dust and guards prevent it from being accidentally closed. Plenty of finger room is available on the rear handle and a second handle, below which is the spindle-locking button, can be mounted on either side of the tool. A metal strap supports the tool in a safe position when it is not in use and an eyebolt allows it to be used in a suspended position from a balance reel. Two wheel guards are provided, one for use with 7 in. depressed-centre wheels and the other for 9 in. wheels.

To provide the minimum of rotating weight with the maximum flexibility for sanding with 7-in. abrasive discs, the new tool is supplied with a moulded rubber backing pad 5 in. in diameter and a plastic " Koolflex " backing pad 6¾ in. in diameter. For 9 in. discs, an 8¾ in. " Koolflex " pad is available. Should a more rigid backing be required for the larger sanding discs the two pads can be used together.

AIR-CONTROLLED BRAKES FOR MOTOR VEHICLES

LIGHTWEIGHT SYSTEM FOR MEDIUM SIZES

Braking systems utilising air as the operating medium have for some time been available for use on the heavier types of road vehicle. However, a lightweight version is now available which is suitable for vehicles of medium weight. The new equipment is made by the Clayton Dewandre Company, Limited, Titanic Works, Lincoln, to American Bendix Westinghouse designs.

The three new components for the system are the compressor, the type E brake valve and the actuator, for the system is a double one in that the air is used to control a hydraulic system which in turn actually operates the brakes. The use of air as the intermediate medium gives both fineness and smoothness of control. Apart from the three components mentioned, the remainder are the same as for the heavier equipment.

Two models of the new compressor are made, one being self-lubricated and the other being linked into the engine lubrication system. The latter, having no separate sump, is slightly smaller and measures 7½ in. in height with a weight of 12 lb. The former is shown in Fig. 1; it is 2 lb. heavier. The bore and stroke of these compressors (which are designated Tu-Flo 300) are 1¾ in. and 1 5/16 in. respectively. At 1,250 r.p.m. they have a piston displacement of 4 cub. ft. per minute; the maximum speed is 3,000 r.p.m. They are air cooled and can be driven in either direction. The crankcase is aluminium, the cylinder block and head are cast iron and the crankshaft, which is balanced, is of alloy cast iron. The design departs from American practice in two points: the inlet valves and the unloader valves. The former are spring-loaded flat discs located in the cylinder head. This position provides better cooling, contributes to improved volumetric efficiency and permits a simple mechanism for the unloader valve to be used.

The unloader mechanism in these units consists of two spring-loaded pistons located in the cylinder block. The cavity below the pistons is in communication with the governor which, in turn, is piped to the reservoir. When air pressure in the governor reaches the desired maximum (which is usually between 100 and 105 lb. per square inch) the governor operates and allows air from the reservoir to pass to the unloader cavity and act upon the pistons. These then move against their springs and unseat the inlet valves. Thus the compressor runs idle until the reservoir pressure falls to between 80 and 85 lb. per square inch, when the governor cuts out, the pistons move back under the spring load and the inlet valves return to their seats.

Brake operation is controlled by the brake valve which is shown in section in Fig. 2. It has a pressed-steel pedal with a corrugated non-skid tread. The valve body is die-cast aluminium. In the illustration, the exhaust port is at the upper right, the air inlet at the bottom, and the connection to the actuator lower right. When the pedal is partially depressed, pressure is exerted through the pressure-setting spring to the floating piston, the hollow stem of which closes on the rubber-faced inlet exhaust disc valve to seal the exhaust connection. The valve is then unseated, permitting air to flow from the reservoir, through the valve, to the air-hydraulic actuator to operate the brakes.

When the pressure in the air-hydraulic actuator and below the piston is sufficient to overcome the mechanical force being exerted on the top of the piston, the latter rises, allowing the disc valve to close on its seat to shut off further supply. At the same time the disc valve maintains contact with the hollow piston stem, preventing any loss of pressure, and a balance is achieved in the system. Further depression of the pedal allows a repetition of the cycle until a new point of balance is reached.

When the pedal is released the mechanical force on top of the piston is reduced. Air pressure below the piston causes it to lift and the disc valve is reseated. Further upward movement of the piston lifts the hollow valve plunger from the face of the disc valve and air in the actuator can escape through the hollow plunger and exhaust port to atmosphere, releasing the brakes.

The brake valve is set to graduate between 5 and 75 lb. per square inch. The first 3 degrees of treadle movement permit the valve to deliver 5 lb. per square inch pressure, and the next 17 degrees cover the graduating range. If there is any treadle movement after the first 20 degrees the valve will deliver full reservoir pressure.

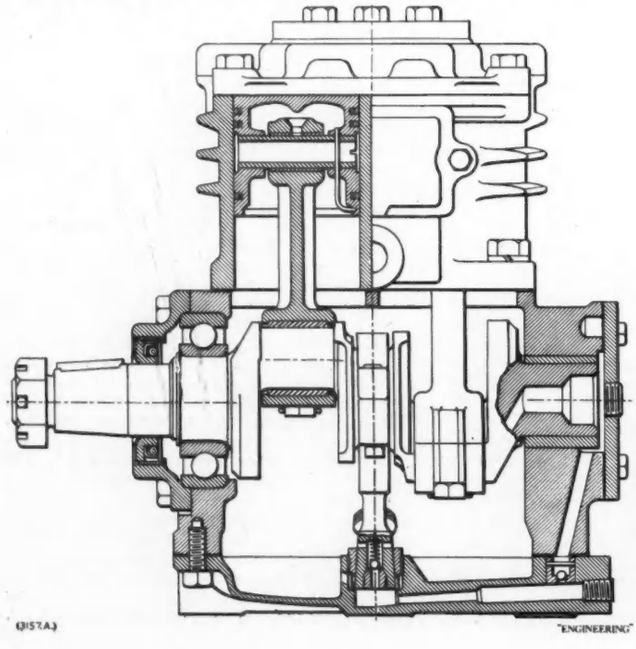


Fig. 1 The compressor is air-cooled and has a displacement of 4 cub. ft. per min. at 1,250 r.p.m. Two models are made: with separate lubrication as shown here, or for linking it to the main engine lubrication system.

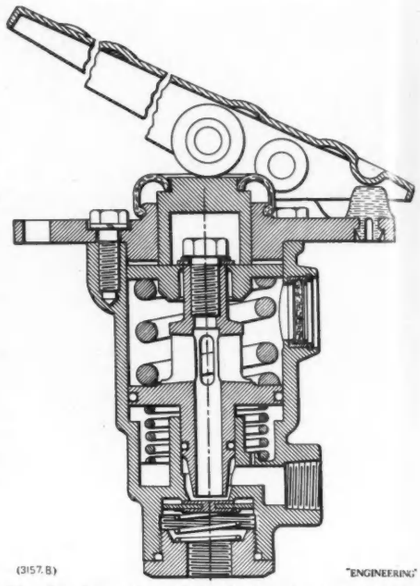


Fig. 2 Operation of the brakes is controlled by the brake pedal. The air pressure applied to the hydraulic actuator is directly proportional to the depression of the pedal.

As well as ensuring that delivered pressure is directly proportional to the degree of treadle movement, the valve is immediately responsive to the driver's control.

The air-hydraulic actuators are made in a range of sizes and mountings to suit standard hydraulic master cylinders. The actuators are dirt-proof, require no lubrication and practically no maintenance. The unit consists of two plates between which a diaphragm is secured by means of a clamp ring. When air under pressure is admitted into the actuator the diaphragm is forced forward, carrying with it a push rod which actuates the hydraulic master cylinder. When the brake pedal is released and air exhausted from the actuator, the push rod is returned by spring action.

A hydraulic master cylinder is directly coupled to the actuator by means of a combination adaptor and mounting bracket. Maximum hydraulic pressures are pre-determined and positively controlled within safe limits. With the available range of actuators the air brake system is able to produce various hydraulic line pressures and fluid displacements while retaining the standard air-brake system pressure of 85–105 lb. per square inch. Sizes are available which will give hydraulic line pressures between 610 and 1,960 lb. per square inch for an air-line pressure of 100 lb. per square inch.

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VACUUM GAUGE FOR TESTING PUMPS

The Pulsometer Engineering Company, Limited, Nine Elms Iron Works, Reading, have introduced a McLeod gauge of robust design for the routine testing of vacuum pumps.

Conventional laboratory-type glass gauges are often inadequately protected and too fragile for the daily requirements of continuous heavy testing. Though it is impossible to avoid the comparatively fragile gauge head, the Pulsometer McLeod gauge type G employs a shrouded case for the glass part, and robust metal tubes for the barometric leg and mercury container.

Gauge heads are produced to a standard calibration so that standard charts may be used and replaceable heads can be employed with existing charts with a minimum margin of error. Standard ranges are from 0·1 to 0·00001 mm. and 10 to 0·01 mm.

The method of operation is by displacement with a wooden plunger which gives a fine control with easy operation. The unit weighs 35 lb.

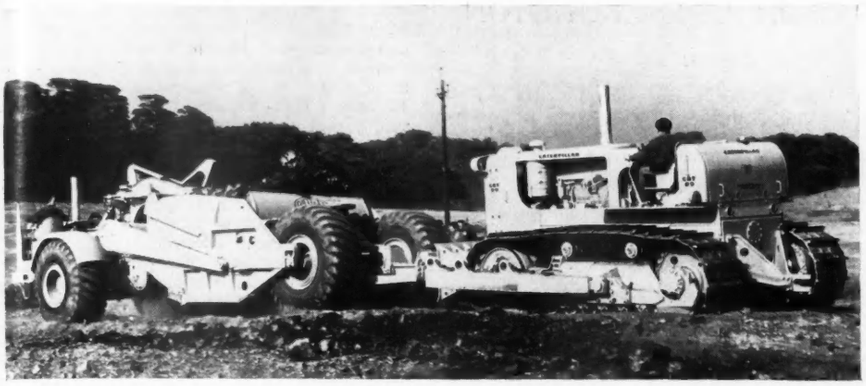

Fig. 1 The D9 tractor with torque-converter drive was used to push-load DW21C scrapers. It took approximately 40 seconds to take on a load of 23 cubic yards.

EARTH MOVING EQUIPMENT

Demonstration at Open-cast Mining Sites

A demonstration was recently arranged by all the British suppliers of the products of the Caterpillar Tractor Company to show the capabilities of the D9 tractor, the introduction of which was recently announced. The first two to reach this country were shown on two open-cast coal sites near Barnsley, Yorkshire—one at which the overburden was being removed following the removal of top soil, and the other where work had been in progress for some time and the workings were two-thirds filled in. At the latter site another new Caterpillar product, the PR21 dumper, illustrated in Fig. 2, was shown being filled by an excavator at the lowest level of the workings and dumping its load to refill the worked-out part.

The D9 crawler tractor, of which a description was given in ENGINEERING, vol. 179, page 606, 1955, was developed by the Caterpillar Tractor Company of Peoria, Ill., U.S.A., in response to a demand for a tractor larger than the D8. The D9 has a horse-power at the flywheel of 286 and at the drawbar of 230. The six-cylinder engine is supercharged by an exhaust turbo-charger and runs at 1,200 r.p.m. One of the two on display had a direct drive using oil clutches, but on the other the drive was through a three-stage torque converter. At the demonstration, the former was shown hauling a Birtley 90 scraper, and the latter was push-loading two DW21C scrapers. This operation is shown in Fig. 1. Later in the day the two tractors were shown operating with Birtley bulldozing blades—one of 7 and the other of 9 cub. yards capacity.

Although the power of the D9 is greater than that of the D8 (230 h.p. as against 155), the weight per horse power is approximately the same and the ground pressure no greater. The all-up weight is approximately 25 tons (56,200 lb.), when in full working order. In both models there is a wide range of operating speeds. The direct drive version has six forward and reverse gears with a maximum speed of 6·8 m.p.h. in both directions. With the torque-converter model there are three forward gears giving speeds ranging from 0 to 4·1, 0 to 5·7 and 0 to 7·8 m.p.h., but only two ranges in reverse, from 0 to 4·1 and from 0 to 7·8 m.p.h. The torque ratio of the converter is 5 to 1.

During the demonstration, the direct drive D9 had little difficulty in loading unassisted the No. 90 scraper with the dry clayey overburden. This scraper has a capacity of 27 cub. yards and it took approximately 2 minutes to obtain a full load. The two DW21C scrapers, which were being push-loaded by the torque-converter D9, are a more powerful version of the DW21, being rated at 300 h.p. These have a struck capacity of 15 cub. yards and heaped of 20 cub. yards. Side boards increase these figures to 18 cub. yards and 23 cub. yards respectively. The average time required to gather a full load was approximately 40 seconds and speeds on the flat of 20 m.p.h. were attained. Like the No. 90, these scrapers are also of Birtley manufacture. It is understood, however, that both types are to be replaced by low-bowl models.

At the second site, the lowest coal seam was being uncovered at a depth of about 160 ft. At the bottom a Lima excavator was loading a fleet of dumpers, one of which was the new PR21. This is made up from a DW21 two-wheel tractor of 275 h.p. and an Athey rear dumping truck of 31 tons capacity or 22½ cub. yards (heaped). The dumping action of this truck is such that as the body tilts, the rear wheels are drawn forward with a consequent shortening of the wheelbase. The maximum angle of tilt is 60 deg. On the site the PR21, which can turn in 34 ft., was taking its full load up a steep gradient, some parts being 1 in 6, and dumping it to fill the exhausted workings. The overburden here was shale. At both these sites the main contractors were Ruddock and Meighan Limited, Barford House, Harrow View, Wealdstone, with whose co-operation the demonstration was arranged and with the consent of the National Coal Board.

Fig. 2 With a load capacity of 31 tons, the PR21 dumper carried shale overburden up a gradient of 1 in 6 to the dumping site.

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EXCAVATOR EXPORTS

The firm of Thomas Smith and Sons (Rodley), Limited, Rodley, Leeds, recently celebrated the dispatch of the hundredth bucket excavator to Canada, and also of the hundredth dragline excavator to New Zealand. The Canadian total has been reached in five years, and the New Zealand total since the war.

MARINE RADIO SERVICE DEPOT

For the benefit of vessels using the Tyne, the Marconi International Marine Communication Company, Limited, have opened new and larger premises in Melbourne-street, Newcastle-upon-Tyne. At these premises, repair work will be carried out on ships' radio equipment, and spares will be held, not only for the immediate neighbourhood, but also for supply to depots farther north. This last will enable equipment to be supplied more quickly to the northern centres than is possible with the present arrangement by which all stock comes from the London area.

In the new buildings there are facilities for testing and overhauling radio, radar and direction finding equipment as well as such other items as ship's broadcast sets and intercommunication telephones. The repair room has four alternative supplies, with switch plugs at each working position, of 230 volts alternating current, and 240 volts, 110 volts, and 24 volts direct current. These supplies are produced from rotary alternators housed in a separate room. On the roof are mounted aerials for the different equipments, including two radar scanners, direction finding loops and radio transmitting and receiving aerials for the various frequencies. Some of them can be seen in the illustration. Radio communication is also possible with the service vans when the latter are operating at the dockside.

Owing to the varied nature of the equipment to be serviced, the range of spares carried has to be large. The items vary from single screws to complete sets ready for installation. By the rental system which is available, the firm are responsible for maintaining the sets in good order, and for training and supplying the operators. At the conclusion of each voyage, the operators report to the depot and record their comments on the general behaviour of the equipment as well as any specific faults which may have occurred. In addition, all financial aspects of the radio-telegraphic services have to be recorded, and Marconi Marine are responsible for clearing the accounts. This last work is actually done at Chelmsford, but there has to be a considerable office staff at Newcastle to cover the paper work. The buildings include separate offices for the administration staff and a lecture room used during the training of operators. Also in the same building there is accommodation for office and repair facilities for the English Electric Company Limited, and Marconi Instruments Limited, both of which operate separately. The building has been designed to allow for possible future expansion by the addition of another storey.

On the roof of the Marconi Marine depot at Newcastle are aerial arrays for testing all the different types of set in use.

ROLLING-MILL MODERNISATION AT WORKINGTON

Electric Drive Replaces Steam

A scheme for modernising their rolling-mill plant producing rails and other railway materials, has been put in hand by the Workington Iron and Steel Company, a branch of the United Steel Companies, Limited, Sheffield. The principal features of the scheme, which is to cost over £1,000,000, are the electrification of the 32 in. roughing and 28 in. finishing stands of the rail rolling mill, and the reconstruction of the 22 in. fish-plate mill. This entails the re-siting of the mill stands and extensive building alterations. It is hoped to complete the reconstruction of the fish-plate mill by the end of the present year, while the replacement of the existing steam engines driving the roughing and finishing stands of the rail mill is scheduled for completion by next May. The entire scheme has been planned to cause the minimum interference to current production.

ROLLING-MILL MOTORS

Both the roughing and finishing-mill steam-engine drives were installed many years ago and are now obsolescent. By installing electric motors, higher outputs will be possible and the re-siting of the roughing and finishing stands 40 ft. further away from the cogging mill will enable the ingot weight to be increased from 3 to 3½ tons, thus yielding—in the case of a 109 lb. per yard flat-bottom rail—three rails per ingot instead of the present two rails. Substantial economies in maintenance costs and fuel consumption are also envisaged.

The new roughing drive will be a 2,750 h.p. reversing direct-current motor having a speed range of 0 to 50 r.p.m., and 50 to 100 r.p.m. For the finishing drive, a 2,500 h.p. reversing direct-current motor is being provided. This will have a speed range of 0-60 r.p.m., and 60 to 120 r.p.m. Both motors and all the associated electrical equipment are being supplied by the English Electric Company, Limited.

Two 25 ton electric overhead cranes to facilitate roll changing, a new down-cutting billet shear with depression table, and other equipment are also to be installed.

FISH-PLATE MILL

The present 22 in. fish-plate mill is a very old one and is being replaced by a modern 18 in. mill having three three-high stands and totally-enclosed pinions. The new mill will take a larger billet than the old, up to 9 ft. in length, and this will enable the output to be increased from 7,800 tons to 11,400 tons per annum. The reconstruction of the mill is being undertaken by the Brightside Foundry and Engineering Company, Limited.

The existing 1,200 h.p. steam-engine drive is being retained and as the mill at present occupies the proposed site for the new roughing-mill electric drive, it is being transferred some 80 ft. away from its present position. At the same time, the associated reheating furnace is being replaced by a new installation. The new furnace will be equipped with electrically-driven charging and pushing apparatus and will be capable of re-heating 50 tons of billets in an eight-hour shift. It will be fired by coke-oven gas, the hearth dimensions being 34 ft. long by 10 ft. 6 in. wide. The suppliers are Gibbon Brothers (Dudley), Limited.

ROLL-TURNING SHOP

In connection with the reconstruction scheme a new roll-turning shop has been built and is now in use. It is 180 ft. long, 57 ft. wide and 34 ft. high to the eaves. It is equipped with six lathes served by a 25 ton electric overhead travelling crane and the building incorporates several offices, tool rooms and template stores. A new hydraulic pump house has also been built containing three pumps, an air accumulator and three air compressors.

THE "RANGER" MOBILE RADIO-TELEPHONE SYSTEM

Four Systems Used in Frequency Band Formerly Occupied by One

The improved efficiency and economy in the operation of transport vehicles that can result from the use of radio-telephony for communication between the vehicle and its base are so apparent that it is not surprising that the demand for suitable equipment has increased enormously. At the present time, we understand, there are over 10,000 mobile radio-telephones in use in this country. These, however, are operating on a frequency band which is being greatly reduced by recent developments in television and the increased demands for mobile radio-telephony are likely to be restricted as the number of channels available for development diminishes. At present in this country mobile radio-telephone channels are spaced at 100 kc/s, whereas in the United States, where about half a million radio-telephones are in use, the frequency spacing is now 60 kc/s and it is intended to reduce it to 30 kc/s.

To meet the situation and provide as far as possible for the future, Pye Limited, Cambridge, have developed a mobile radio-telephone system, the "Ranger," which can provide two-way communication with a channel spacing of only 25 kc/s, thus making four times as many frequency channels available. The equipment was demonstrated at Russell Hotel, London, on September 27, where four sets with a separation of 25 kc/s were used for telephony without mutual interference. The four base transmitters were erected at Hampstead a distance of about five miles, being controlled by land line from the hotel, and four transmitter-receivers were installed in the hotel, as well as one each in four cars travelling between Hampstead and Russell Square.

The demonstration was entirely satisfactory, four separate conversations being carried on over a period of about 45 minutes without a hitch. The power used in the base transmitters was 15 watts in each case, and in the transmitter-receivers 5 watts. The carrier frequencies used on the former were 161·725, 161·750, 161·775 and 161·800 Mc/s and in the latter 157·225, 157·250, 157·275 and 157·30 Mc/s.

The accompanying illustration shows one of the transmitter-receiver units arranged for dash-board mounting. It measures 9¾ in. wide, 14 in. deep and 5½ in. high, weighs 22 lb., and can operate on a 12-volt or 6-volt supply; the current consumption of the receiver is 3·1 amperes and of the transmitter 4·8 amperes at 12 volts. The transmitter, receiver and power-supply unit are housed in a steel case with a louvred plastic front panel, the latter being provided with a hook rest for the microphone. Also mounted on the front panel are the on-off switch, volume control and standby switch. The pre-set controls comprise receiver and transmitter aerial trimmers, mute circuit, intermediate-frequency gain level adjustment, and receiver crystal trimming condenser. The receiving circuit is of the double-superheterodyne type with efficient noise-limiting characteristics and is designed to ensure that cross-modulation and inter-modulation interference shall be at the lowest possible level. Two crystals and 11 valves are employed in the receiver. The transmitter consists of a crystal oscillator, followed by three multipliers and a power amplifier, the modulator comprising a phase splitter and push-pull modulator. The modulation response is from 300 to 3,000 cycles per second; amplitude modulation is employed.

Transmitter-receiver unit of "Ranger" radio-telephone for dashboard mounting.

It may be noted in conclusion that users of existing equipment will be able to incorporate the Pye "Ranger" equipment in their systems with only slight modifications to the fixed transmitters.

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HYDRO-ELECTRIC DEVELOPMENT IN SCOTLAND

Additions to Tummel Valley Scheme

The Secretary of State for Scotland has confirmed a scheme, prepared by the North of Scotland Hydro-Electric Board, which will enable the annual output of 600 million kilowatt-hours now obtained from the Rivers Tummel and Garry to be increased by about 32·7 million kilowatt-hours.

For this purpose two stations with a total capacity of 3,900 kW are to be built—one at the outlet of the existing tunnel from Loch Garry to Loch Ericht and the other on the Allt cuaich, near Dalwhinnie in Inverness-shire.

The scheme also includes the diversion of several streams into the Board's reservoirs, which will enable another 10 million kilowatt-hours to be generated by means of water stored in Loch Errochty. Further, the aqueduct which now leads water from Dunalastair reservoir to the power station at Tummel Bridge will be enlarged and the water level raised. This will enable the output of that station as well as of those at Clunie and Pitlochry further down the Tummel Valley to be increased.

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AN ELECTRIC TRACTION JUBILEE

The jubilee of the conversion to electric traction of the "Circle" line, which now forms part of the system of London Transport, occurred during September.

The first section of this line was opened in 1863 but was not completed until 1884, when a steam service was provided jointly by the then Metropolitan and District Railways. Both companies began experiments with electrification in 1900, as the result of which it was decided to proceed with the conversion. Disagreement, however, occurred as to the system to be adopted and it was only after a long inquiry that low-tension direct-current operation was selected. In July, 1905, the District completed the conversion of the section between Ealing Broadway and Whitechapel, which included the southern half of the Circle line, while the remainder was converted by the Metropolitan during the week of September 17 to 24 in the same year.

As a result of the conversion it became possible to reduce the running time for the 13-mile journey from 70 to 53 minutes. The latter still remains the scheduled time, in spite of the introduction of automatic signalling, although some trains complete the circle in four minutes less.

NOTICES OF MEETINGS

Association of Supervising Electrical Engineers

LONDON
"Cinema Sound and Projection Equipment," A. H. Richardson. Central London Branch. St. Ermin's Hotel, Caxton-street, S.W.1. Mon., Oct. 10, 7 p.m.
Various short papers by branch members. South West London Branch. Guild House, 32 Worple-road, Wimbledon, S.W.18. Wed., Oct. 12, 8.15 p.m.
HALIFAX
Inaugural Meeting. Film of the Electrical Engineers' Exhibition. Halifax Branch. Crown Hotel, Horton-street, Halifax. Wed., Oct. 12, 7.30 p.m.
STOKE
Discussion on "Metal Rectifiers." Stoke and Crewe Branch. North Stafford Hotel, Stoke. Fri., Oct. 14, 8 p.m.
YORK
"Power Factor Improvement," by R. G. N. Soper. York Branch. Shambles Café, York. Wed., Oct. 12, 7.15 p.m.

British Institution of Radio Engineers

WOLVERHAMPTON
"Frequency Modulation Broadcasting and Reception," by H. E. Farrow. West Midlands Section. Wolverhampton and Staffordshire Technical College, Wulfruna-street, Wolverhampton. Wed., Oct. 12, 7.15 p.m.

Building Centre

LONDON
Film on "Jointing and Fitting of Copper Tube." Wed., Oct. 12, 12.45 p.m.

Chemical Society

SOUTHAMPTON
"Recent Developments in Acetylene and Allene Chemistry," by Professor E. R. H. Jones. Southampton Branch. Chemistry Department, The University, Southampton. Fri., Oct. 14, 5 p.m.

Illuminating Engineering Society

LONDON
Presidential Address by A. G. Higgins. Royal Institution, Albemarle-street, W.1. Tues., Oct. 11, 6 p.m.
SHEFFIELD
Chairman's Address by W. Berry. Sheffield Centre. The University, Western Bank, Sheffield, 10. Mon., Oct. 10, 6.30 p.m.

Incorporated Plant Engineers

BIRMINGHAM
"Aveling Barford Dumper Grader," with film, by P. Stevenson; and film on "Care and Maintenance of Plant." Birmingham Branch. Imperial Hotel, Birmingham. Fri., Oct. 14, 7.30 p.m.
GLASGOW
"Hermetically-Sealed Refrigerating Equipment," by A. K. Alcock. Glasgow Branch. Scottish Building Centre, 425-427 Sauchiehall-street, Glasgow. Thurs., Oct. 13, 7 p.m.
LEICESTER
"Works Accountancy," by D. D. Eade. Leicester Branch. Leicester College of Art and Technology, The Newarkes, Leicester. Wed., Oct. 12, 6.30 p.m.
MANCHESTER
"Steam for Process," by L. G. Northcroft. Manchester Branch. Engineers' Club, Albert-square, Manchester. Tues., Oct. 11, 7.15 p.m.
NEWCASTLE-UPON-TYNE
Film Evening. North East Branch. Roadway House, Oxford-street, Newcastle-upon-Tyne. Thurs., Oct. 13, 7 p.m.
NOTTINGHAM
"Planned Maintenance," by A. S. Stedman. East Midlands Branch. County Hotel, Theatre-square, Nottingham. Wed., Oct. 12, 7 p.m.

Institute of British Foundrymen

BEDFORD
Presidential Address; and "Some Castings from a Jobbing Foundry," by A. F. Hammond. Bedfordshire and Hertfordshire Section. Works of W. H. Allen, Sons & Co., Ltd., Bedford. Thurs., Oct. 13, 7.30 p.m.
GLASGOW
"Machinability," by J. M. Douglas. Scottish Branch. Royal Technical College, Glasgow. Wed., Oct. 12, 7.30 p.m.
LINCOLN
Presidential Address by E. C. Carrott; and "Hot-Blast Cupolas," by C. A. Payne. Lincolnshire Branch. Technical College, Lincoln. Thurs., Oct. 13, 7.15 p.m.

Institute of Fuel

GLASGOW
"Development of Slurry-Handling Plant at Barony Power Station," by J. R. Croucher. Scottish Section. Royal Technical College, Glasgow. Fri., Oct. 14, 7 p.m.
NEWCASTLE-UPON-TYNE
"Coal Preparation and Evaluation," by J. K. Matthews. North Eastern Section. King's College, Newcastle-upon-Tyne. Mon., Oct. 10, 6.30 p.m.

Institute of Marine Engineers

LONDON
"Passenger Liner with Engines Aft," by R. K. Craig. Tues., Oct. 11, 5.30 p.m.
BIRMINGHAM
"Steam Boilers: Trends and Tendencies," by G. A. Plummer. West Midlands Section. Birmingham Exchange and Engineering Centre, Stephenson-place, Birmingham, 2. Thurs., Oct. 13, 7 p.m.
GLASGOW
"From River Bottom to Sea Bed," with film, by D. W. Low. Scottish Section. Institution of Engineers and Shipbuilders, 39 Elmbank-crescent, Glasgow, C.2. Wed., Oct. 12, 7.30 p.m.
LIVERPOOL
"La Mont Boilers," by G. A. Plummer. Merseyside and North Western Section. Picton Hall, William Brown-street, Liverpool. Wed., Oct. 12, 6.30 p.m.

Institute of Petroleum

LONDON
"The Application of Cost Accounting to Oil Operations," by C. J. Taylor. Wed., Oct. 12, 5.30 p.m.

Institute of Road Transport Engineers

LONDON
Annual General Meeting and Film Evening. Royal Society of Arts, John Adam-street, Adelphi, W.C.2. Tues., Oct. 11, 6.30 p.m.
BIRMINGHAM
"Use and Abuse of Tyres," by G. H. I. List. Midlands Centre. Birmingham Exchange and Engineering Centre, Stephenson-place, Birmingham, 2. Tues., Oct. 11, 7.30 p.m.
CARDIFF
"Metal Spraying and Reclamation," by Lloyd Manuel. South Wales Group. South Wales Institute of Engineers, Park-place, Cardiff. Fri., Oct. 14, 7 p.m.
LIVERPOOL
"Commer Two-Stroke Diesel Engines," by E. W. Coy. West Regional Centre. Adelphi Hotel, Lime-street, Liverpool. Thurs., Oct. 13, 7.30 p.m.

Institute of Welding

LONDON
"Progress Towards Eliminating Brittle Fracture in Steel Structures," by Dr. A. A. Wells. South London Branch. E.L.M.A. Lighting Service Bureau, 2 Savoy-hill, W.C.2. Thurs., Oct. 13, 6.30 p.m.
CHATHAM
Brains Trust Meeting. Medway Section. Sun Hotel, Chatham. Wed., Oct. 12, 7.45 p.m.

Institution of Chemical Engineers

CHESTER
"A Pilot Plant Employing a Novel Process for the Urea Extraction of Hydrocarbons," by L. N. Goldsbrough. North Western Branch. The Grosvenor Hotel, Chester. Tues., Oct. 11, 7 p.m.

Institution of Civil Engineers

LONDON
"The Failure of Repair of Ridham Dock," by R. G. T. Lane and G. T. Gregorian. Tues., Oct. 11, 5.30 p.m.
MANCHESTER
Chairman's Address by J. D. T. Firth. North Western Association. Engineers' Club, Albert-square, Manchester. Thurs., Oct. 13, 6.30 p.m.

Institution of Electrical Engineers

LONDON
Chairman's Address on "Alternating-Current Switchgear," by M. H. F. Collins. London Graduates' and Students' Section. Mon., Oct. 10, 6.30 p.m.
Chairman's Address by W. Bamford. Measurement and Control Section. Tues., Oct. 11, 5.30 p.m.
Chairman's Address by D. B. Hogg. Utilization Section. Thurs., Oct. 13, 5.30 p.m.
CARDIFF
Chairman's Address by T. G. Dash. Western Centre. South Wales Institute of Engineers, Park-place, Cardiff. Mon., Oct. 10, 6 p.m.
FARNBOROUGH
James Clayton Lecture on "Nuclear Reactors and Power Production," by Sir Christopher Hinton. Southern Centre. Royal Aircraft Establishment Technical College, Farnborough. Wed., Oct. 12, 7.30 p.m.
LOUGHBOROUGH
Chairman's Address by F. R. C. Roberts. Annual General Meeting. East Midland Centre. Loughborough College, Loughborough. Tues., Oct. 11, 7 p.m.
NEWCASTLE-UPON-TYNE
Chairman's Address. North Eastern Centre. Neville Hall, Westgate-road, Newcastle-upon-Tyne. Mon., Oct. 10, 6.15 p.m.

Institution of Heating and Ventilating Engineers

LONDON
"Engineering Services at the British European Airways Maintenance Hangars at London Airport," by L. Copeland Watts and J. W. J. Leslie. Institution of Mechanical Engineers, 1 Birdcage-walk, St. James's Park, S.W.1. Wed., Oct. 12, 6 p.m.
BRISTOL
"Oil Burners for Small Boilers," by G. L. Gollin and A. Kenyon. South Western Branch. R.W.A. School of Architecture Library, Bristol. Tues., Oct. 11, 6.30 p.m.
LIVERPOOL
"Feed and Vent Pipes," by R. Hayes. Liverpool Branch. College of Building, Clarence-street, Liverpool. Wed., Oct. 12, 6.30 p.m.

Institution of Mechanical Engineers

LONDON
Presidential Address by P. L. Jones. Fri., Oct. 21, 5.30 p.m.
"Filtration for Internal-Combustion Engines," by P. A. Hawkins. London Graduates' Section. Thurs., Oct. 13, 6.30 p.m.
DERBY
"Post-Graduate Training," by J. F. N. McNair. East Midlands Graduates' Section. Museum and Art Gallery, Derby. Mon., Oct. 10, 7.15 p.m.
GLASGOW
"Development of Power-Station Design," by C. W. Marshall. Scottish Branch. Royal Technical College, George-street, Glasgow. Thurs., Oct. 13, 7.30 p.m.
LINCOLN
"Combustion in Compression-Ignition Oil Engines," by Professor S. J. Davies, read by M. A. Plint. East Midlands Branch. Technical College, Lincoln. Wed., Oct. 12, 7.30 p.m.
SHEFFIELD
"Rubber in Mechanical Engineering," by E. C. Brookes. Yorkshire Graduates' Section. The University, Sheffield. Tues., Oct. 11, 6.30 p.m.
SWANSEA
Chairman's Address by T. S. Charleson. South Wales Branch. Mackworth Hotel, Swansea. Tues., Oct. 11, 6 p.m.

Institution of Production Engineers

COLCHESTER
"Ball and Roller Bearings: Their Application and Manufacture," by A. R. Watson. Eastern Counties Section. Britannia Works of Davey Paxman & Co., Ltd., Colchester. Fri., Oct. 14, 7.30 p.m.
DARLINGTON
"Practical Uses of Electronics in Industry," by K. A. Zandstra. Tees-Side Section. Technical College, Darlington. Tues., Oct. 11, 7 p.m.
DONCASTER
"Centrifugal Casting and Shell Moulding," by Dr. L. Harrison. Doncaster Section. Danum Hotel, Doncaster. Tues., Oct. 11, 7 p.m.
HUDDERSFIELD
"Automation: New Tools for Higher Productivity," by F. G. Woollard. Halifax Section. George Hotel, Huddersfield. Mon., Oct. 10, 7.15 p.m.
LEICESTER
Chairman's Address "On Being a Production Engineer," by J. C. Routledge. Leicester Section. Bell Hotel, Leicester. Thurs., Oct. 13, 7 p.m.
LIVERPOOL
"The Application of Radio-Isotopes in Industry," by Dr. Henry Seligman. Liverpool Section. Exchange Hotel, Liverpool. Wed., Oct. 12, 7.30 p.m.

Institution of Structural Engineers

LONDON
"Load Tests on a Three-Storey Reinforced-Concrete Building in Johannesburg," by Professor A. J. Ockleston. Thurs., Oct. 13, 6 p.m.
GLASGOW
Chairman's Address by Professor W. T. Marshall. Scottish Branch. Ca'doro Restaurant, Union-street, Glasgow. Mon., Oct. 10, 6 p.m.
NEWCASTLE-UPON-TYNE
"Relationship Between Structural and Civil Engineering," by E. A. Parsons. Northern Counties Branch. Offices of the Northern Gas Board, Grainger-street, Newcastle-upon-Tyne. Wed., Oct. 12, 6.30 p.m.

Institution of Works Managers

BIRMINGHAM
"Has the Public Health Department a Part to Play in Industrial Health?" by Dr. E. L. M. Millar. Birmingham Branch. Birmingham Exchange and Engineering Centre, Stephenson-place, Birmingham. Tues., Oct. 11, 7 p.m.

Junior Institution of Engineers

LONDON
"Some Interesting Axial-Flow Fan Applications," by R. C. Dick. Fri., Oct. 14, 7 p.m.
SHEFFIELD
Chairman's Address; and "Industrial-Hygiene Engineering," by G. F. H. Peacock. Annual General Meeting. Sheffield Section. Livesey Clegg House, Union-street, Sheffield. Mon., Oct. 10, 7.30 p.m.

Newcomen Society

LONDON
"George Jackson Churchward, Chief Mechanical Engineer, Great Western Railway: The Man and His Work," by Sir William Stanier. Wed., Oct. 12, 5.30 p.m.

North East Coast Institution of Engineers and Shipbuilders

NEWCASTLE-UPON-TYNE
"Impact of the Development of Atomic and Thermo-Nuclear Weapons on the Royal Navy," by Commander J. R. H. Bull. Literary and Philosophical Society, Newcastle-upon-Tyne. Fri., Oct. 14, 6.15 p.m.

Reinforced Concrete Association

LONDON
"Some Recent Developments in the Technique of Precasting Concrete Structures," by J. A. Derrington. Institution of Structural Engineers, 11 Upper Belgrave-street, S.W.1. Wed., Oct. 12, 6 p.m.

Royal Meteorological Society

LUTON
"Clouds," by F. H. Ludlam. Luton Girls' High School, Luton. Tues., Oct. 11, 5.30 p.m.

Royal Society for the Promotion of Health

BURY
"Treatment of Gaseous and Liquid Effluents from the Manufacture of Regenerated Cellulose Film," by C. B. Roberts and "The Promotion of Health," by Dr. K. K. Wood. Municipal Technical College, Bury. Thurs., Oct. 13, 10 a.m.

Royal Statistical Society

LONDON
"A Research Design for Studying the Effects of Television," by W. A. Belson. Study Section. Lighting Service Bureau, 2 Savoy-hill, W.C.2. Wed., Oct. 12, 6 p.m.

Sheffield Metallurgical Association

SHEFFIELD
"Introductory Talk on Electric Furnaces, with Particular Reference to Refractories," by F. T. Bagnall. B.I.S.R.A. Laboratories, Hoyle-street, Sheffield, 3. Tues., Oct. 11, 7 p.m.

The address and telephone number of the headquarters of each institution are given below. Meetings in the headquarters town are held there unless otherwise stated. Particulars for this column should reach the Editor not later than Monday morning in the week preceding the date of the meeting.

Association of Supervising Electrical Engineers, 23 Bloomsbury-square, London, W.C.1. (LANgham 5927.)
British Institution of Radio Engineers, 9 Bedford-square, London, W.C.1. (MUSeum 1901.)
Building Centre, 26 Store-street, London, W.C.1. (MUSeum 5400.)
Chemical Society, Burlington House, Piccadilly, London, W.1. (REGent 0675.)
Illuminating Engineering Society, 32 Victoria-street, London, S.W.1. (ABBey 5215.)
Incorporated Plant Engineers, 48 Drury-lane, Solihull, Birmingham. (Solihull 3021.)
Institute of British Foundrymen, St. John Street Chambers, Deansgate, Manchester 3. (Blackfriars 6178.)
Institute of Fuel, 18 Devonshire-street, Portland-place, London, W.1. (LANgham 7124.)
Institute of Marine Engineers, 85 The Minories, London, E.C.3. (ROYal 8493.)
Institute of Petroleum, Manson House, 26 Portland-place, London, W.1. (LANgham 2250.)
Institute of Road Transport Engineers, 69 Victoria-street, London, S.W.1. (ABBey 6248.)
Institute of Welding, 2 Buckingham Palace-gardens, London, S.W.1. (SLOane 9851.)
Institution of Chemical Engineers, 56 Victoria-street, London, S.W.1. (VICtoria 6161.)
Institution of Civil Engineers, Great George-street, London, S.W.1. (WHItehall 4577.)
Institution of Electrical Engineers, Savoy-place, Victoria-embankment, London, W.C.2. (TEMple Bar 7676.)
Institution of Heating and Ventilating Engineers, 49 Cadogan-square, London, S.W.1. (SLOane 3158.)
Institution of Mechanical Engineers, 1 Birdcage-walk, St. James's Park, London, S.W.1. (WHItehall 7476.)
Institution of Production Engineers, 10 Chesterfield-street, London, W.1. (GROsvenor 5254.)
Institution of Structural Engineers, 11 Upper Belgrave-street, London, S.W.1. (SLOane 7128.)
Institution of Works Managers, 67-68 Chandos-place, London, W.C.2. (TEMple Bar 8324.)
Junior Institution of Engineers, Pepys House, 14 Rochester-row, London, S.W.1. (VICtoria 0786.)
Newcomen Society, Science Museum, Exhibition-road, London, S.W.7. (KENsington 1793.)
North East Coast Institution of Engineers and Shipbuilders, Bolbec Hall, Newcastle-upon-Tyne 1. (Newcastle 20289.)
Reinforced Concrete Association, 94-98 Petty France, London, S.W.1. (ABBey 4504.)
Royal Meteorological Society, 49 Cromwell-road, South Kensington, London, S.W.7. (KENsington 0730.)
Royal Society for the Promotion of Health, 90 Buckingham Palace-road, London, S.W.1. (SLOane 5134.)
Royal Statistical Society, 21 Bentinck-street, London, W.1. (WELbeck 7638.)
Sheffield Metallurgical Association, 15 Crescent-road, Sheffield 7. (Sheffield 53674.)

THE HUMAN ELEMENT

Wage claims looming ahead. Earnings are already high; dividends are, too, but not compared with pre-war figures. A fear of redundancy from automation. Railway unions preparing for wage demands. Unions faced with need for higher contributions. Strikes—where they start and how they might be avoided.

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Wage Claims in November

The anticipated wage claims for about £147 million in the building and engineering industries are likely to be put forward in November. It is also possible that the railwaymen will press theirs at about the same time. There is no doubt that all will meet with the stiffest opposition. But the winter is expected to bring to a head the country's difficulties and it may be that a nation-wide appeal for restraint and sacrifice will succeed. Only an enlightened public opinion and the promotion of mutual trust between employers and workers can now avoid a bitter and wasteful conflict.

There is, of course, an element in union leadership which will wield what influence it has in favour of restraint. Mr. R. Oppenshaw, president of the A.E.U., said last April that a new wage demand "would be very misguided judgment." But leadership, whether union or political, will not easily allay suspicions that the sacrifices called for are one-sided. A most serious warning was given by Sir Harry Railing, chairman of the General Electric Company, last week: if the demands for more pay, less hours and longer holidays are granted to his company's 47,000 workers they will add 10 per cent. to the cost of their products and "would be the best way to price us out of the export markets." But who will tell this to the people and have them believe it?

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Earnings and Dividends

During the past twelve months the rise in wages and earnings has outstripped the rise in industrial production: the industrial production index rose by 6 per cent., wage rates by 8 per cent. and earnings by rather more. This disparity will be increased if the wage claims now being pressed or pending are granted, even in part, and since several are from workers who have not had an increase for over a year they will be hard to turn down. Yet the threat to British exports is very real.

There is now little doubt that a major balance-of-payments crisis is building up: we must either export more or import less. There are still a good many things the Government can do —for example, cut public expenditure on arms and services, reduce subsidies, cut down import quotas for luxury goods. But whatever is done, the shoe will pinch in a good many places. Hardship can hardly be put forward by many of the loudest claimants: the latest official statistics show that miners, dock workers, and men in the metal manufacturing industries earned on the average more than £12 a week in April. Weekly earnings in vehicle building were £1. 2*s.* 7*d.* higher than a year previously; those of men in engineering, shipbuilding and electrical goods industries were £1. 1*s.* 5*d.* higher.

Should the Government pursue the established policy of seeking compromise settlements—in effect splitting the difference—the situation may get out of hand, since output and exports are unlikely to show an immediate proportionate increase. If they decide to ask the unions to restrain their members, then they can hardly resist the inevitable demand for dividend limitation. Dividends have increased considerably more than wages since 1951, though still far behind if 1938 is taken as the base year. But in putting this across to their followers the Government are unlikely to find it easier than union leaders asking their members to put away their wage demands and substitute the Union Jack. Lurking behind all this is the disturbing thought that if all manufacturing concerns were as export conscious and enterprising as some, such issues might never arise.

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In Fear of Automation

The shadow of the automatic factory, or, more precisely, the introduction of automatic transfer machines in motor-vehicle works, was discussed last week in Cowley by the unofficial Shop Stewards' Liaison Committee. Their conditions for the acceptance of these machines were bluntly stated: reduced hours, higher basic rates and "no sackings." Trade union leaders were criticised on the grounds that they needed "waking up" and were "divorced from the rank and file." The shop stewards seemed to share the City's scepticism concerning the motor industry's ability to keep up its output, let alone increase it. They feared, therefore, that the introduction of automatic transfer machines would lead to discharges and to lower wages, and took the opportunity to re-assert their determination to seek a progressive reduction in working hours without loss of pay.

The shop stewards' meeting brought out two important points: first, there is a real fear of redundancy through automation among the rank and file; second, there is a deep mistrust of union leadership on this type of issue. Shop steward action of this kind at a national industry-wide level is a new development in trade union activity and could lead to industry groupings which might cut right across established trade groupings and thus threaten the whole structure of British trade unionism. Also, the suggestion of mounting "united movements from the shop floor" would, if adopted, lead to pressure on some firms to bring wages and working conditions to the level of the best in their industry.

At this stage the T.U.C., or the employers, have little cause for alarm and adequate time to consider carefully the questions that were raised and their implications. They would, however, be most unwise to ignore or brush aside these new developments.

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Railway Pay Claims

Industrial relations on the railways will be tested to the full in the next few months. The National Union of Railwaymen and the Transport and Salaried Staffs Association held preliminary talks last week on the formulation of a new claim for higher wages. The Associated Society of Locomotive Engineers and Firemen is pursuing independently its claims for a series of improvements in terms of employment, and the employees' side of the Railway Shopmen's National Council met last week to formulate a new wage claim.

The situation is likely to be complicated by the unwillingness of the A.S.L.E.F. to respond to the overtures from the N.U.R. to consider joint representations. A joint approach by the three big unions was on the agenda of the meeting between the N.U.R. and the T.S.S.A. last week but it was not discussed. The fact that while these two plan a joint strategy the men of A.S.L.E.F. sit brooding in their tents is an ill omen for everyone. So far as British Railways are concerned they might be at some disadvantage in bargaining if faced with a united demand from all three, but they are probably much worse off when they have to take account of the emotions stirred up by inter-union hostility.

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Union Finance

Inflation is no respecter of persons. It attacks shareholder and operative alike—it also strikes at the union official. Rising costs of administration and the services provided to members have to be met out of union subscriptions, or those services must suffer. This is a hard point for those who are accustomed to think that when costs go up, "they" must pay for them, "they" being anyone but "me". Nevertheless it is becoming evident that union members in general will have to be thinking soon about higher contributions. The latest case of this is the 94,000 membership of the Amalgamated Union of Building Trade Workers which has lost £28,000 in the first half of this year. Although members have rejected once recently a call for higher contributions, they are to be asked to reconsider the position in November.

To-day the financial side of running the larger unions is a major task of administration. Large sums of money are raised and spent and the whole matter has grown far beyond a club basis. The other side of rising costs in a time of inflation is the growing financial power of some of the unions. Years of full employment and shrewd administration have given some unions large funds to invest. It was the miners' proud claim at the annual conference this year at Rothesay that the N.U.M. is now an important shareholder in British industry. Other unions are growing into a similar position. It is to be hoped that some of the less attractive features of big-business unionism in the United States do not develop here, but there is no doubt that the unions are becoming increasingly large as administrative machines and as shareholders. The implications of this on the unions' attitudes to profits, investment and the control of industry will repay careful thought both within the unions and elsewhere. What would happen, for example, if it were suddenly discovered that the miners owned several large engineering companies?

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Talks on Strikes

All three sides on the Joint Advisory Council for Industry (the Government, the employers and the unions) continue to treat with great circumspection the problem of how to avoid strikes. At the last meeting of the Council at the end of July the question was raised tentatively but serious discussion was deferred until everyone had had time to formulate some sort of a view. Preliminary talks were held last week at the meeting of the Joint Consultative Committee, but after an hour-and-a-half the discussion was adjourned until some time in November. Since the last time the matter was raised the two most important developments have been the increased powers given to its General Council by the Trades Union Congress at Southport and the recent manifesto by the British Employers' Confederation.

All this is very valuable so far as it goes for it helps to maintain a climate of good relations among the top official representatives of organised labour and the employers. It has the advantages of continued diplomatic contact—and also the limitations. Strikes do not start at Smith-square any more than they begin at Tothill-street. Sweet reasonableness in the City of Westminster is lost in a vacuum if industrial relations in the factory are not keyed to remove the causes of strikes. It must never be overlooked that although the threat of a nation-wide strike by a powerful union can be averted by diplomacy at the highest level, most strikes are local affairs and must be averted by those who know well the men and the circumstances on the spot.

In August, for example, there was no strike news for the headlines of the national newspapers. Nevertheless, 78,000 working days were lost compared with 67,000 in the same month last year. This was an increase of 17 per cent. Most of the trouble was in coalmining and the motor vehicle industry. Any organised effort from London to avoid strike trouble needs a corresponding effort elsewhere, just as the notable success in productivity propaganda was initiated by the men on both sides at the top but has been carried on with enthusiasm by managers and workers in some industries.